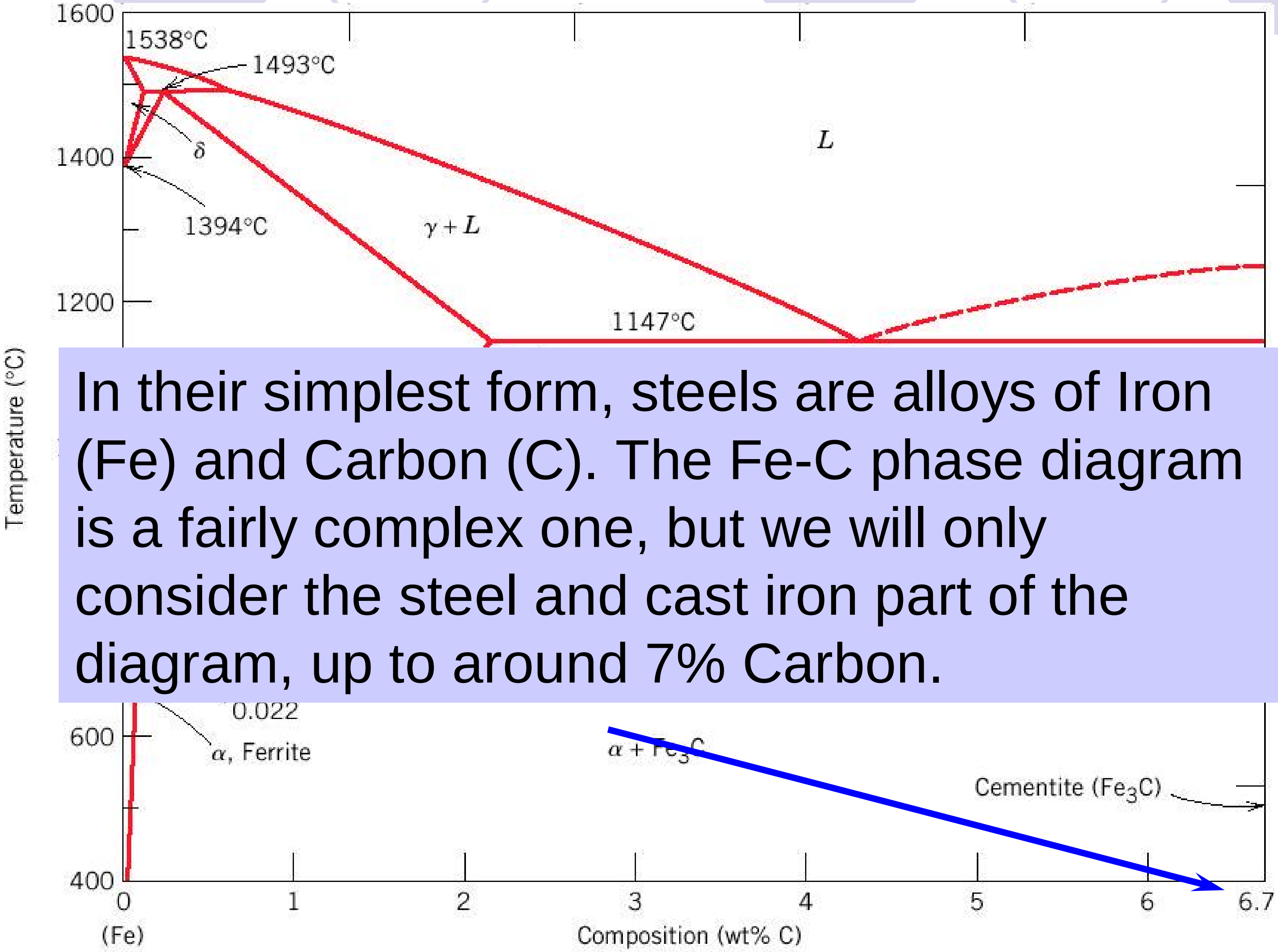
Fe-Fe_3C PHASE DIAGRAM



In their simplest form, steels are alloys of Iron (Fe) and Carbon (C). The Fe-C phase diagram is a fairly complex one, but we will only consider the steel and cast iron part of the diagram, up to around 7% Carbon.

铁碳相图

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IMPORTANCE OF Fe-Fe_3C SYSTEM

- Of all binary alloy systems, the one that is possibly the most important is that for iron and carbon.
- Both steels and cast irons, primary structural materials in every technologically advanced culture, are essentially iron-carbon alloys.
- The focus of this lecture is to study the phase diagram for this system and the development of microstructures.
- The relationships between heat treatment, microstructure, and mechanical properties are based on the phase diagram of this system.

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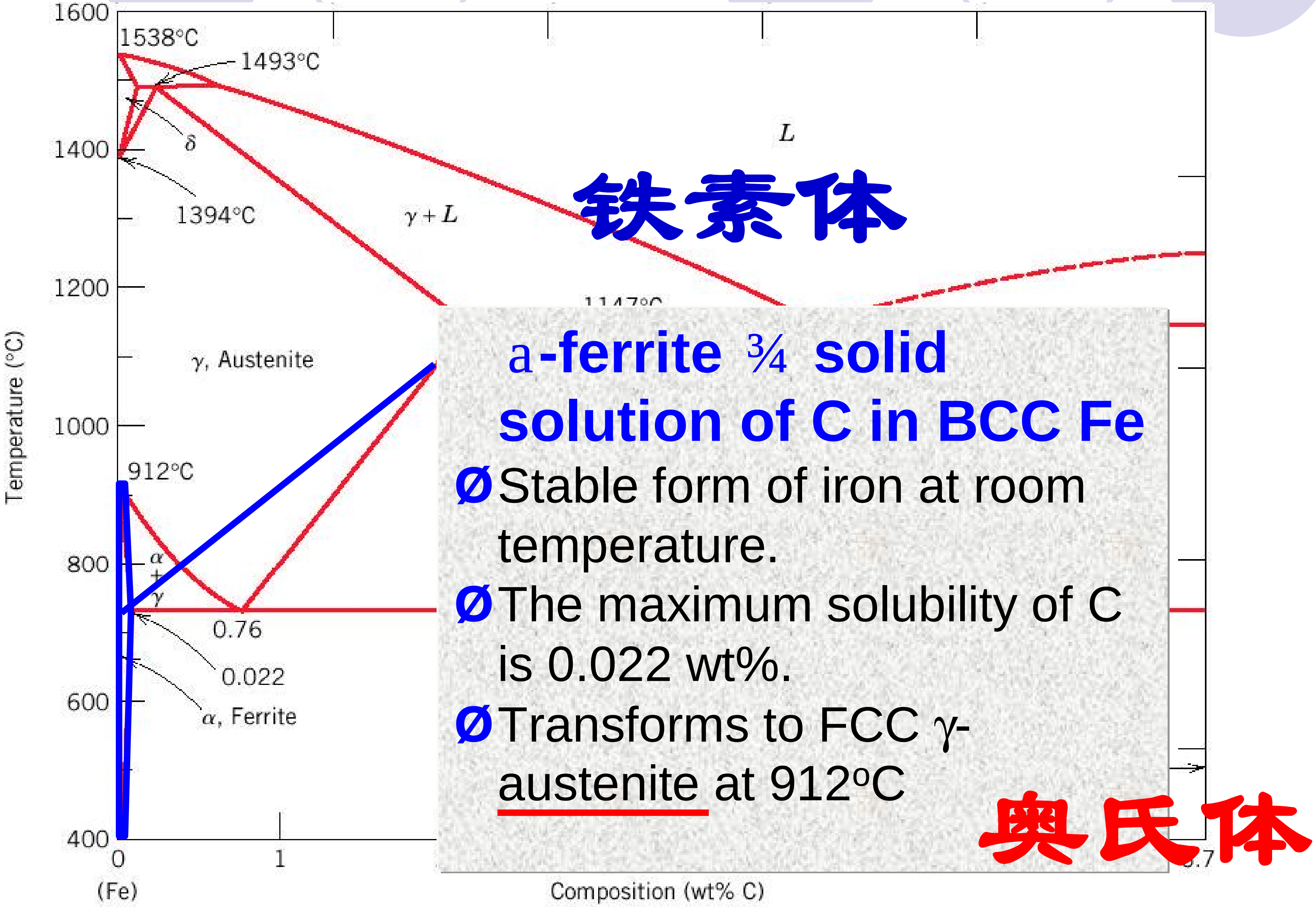
WHAT DO YOU KNOW ABOUT IRON?



a-ferrite ¾ solid solution of C in BCC Fe

- Stable form of iron at room temperature.
- The maximum solubility of C is 0.022 wt%.
- Transforms to FCC γ-austenite at 912^{o}C

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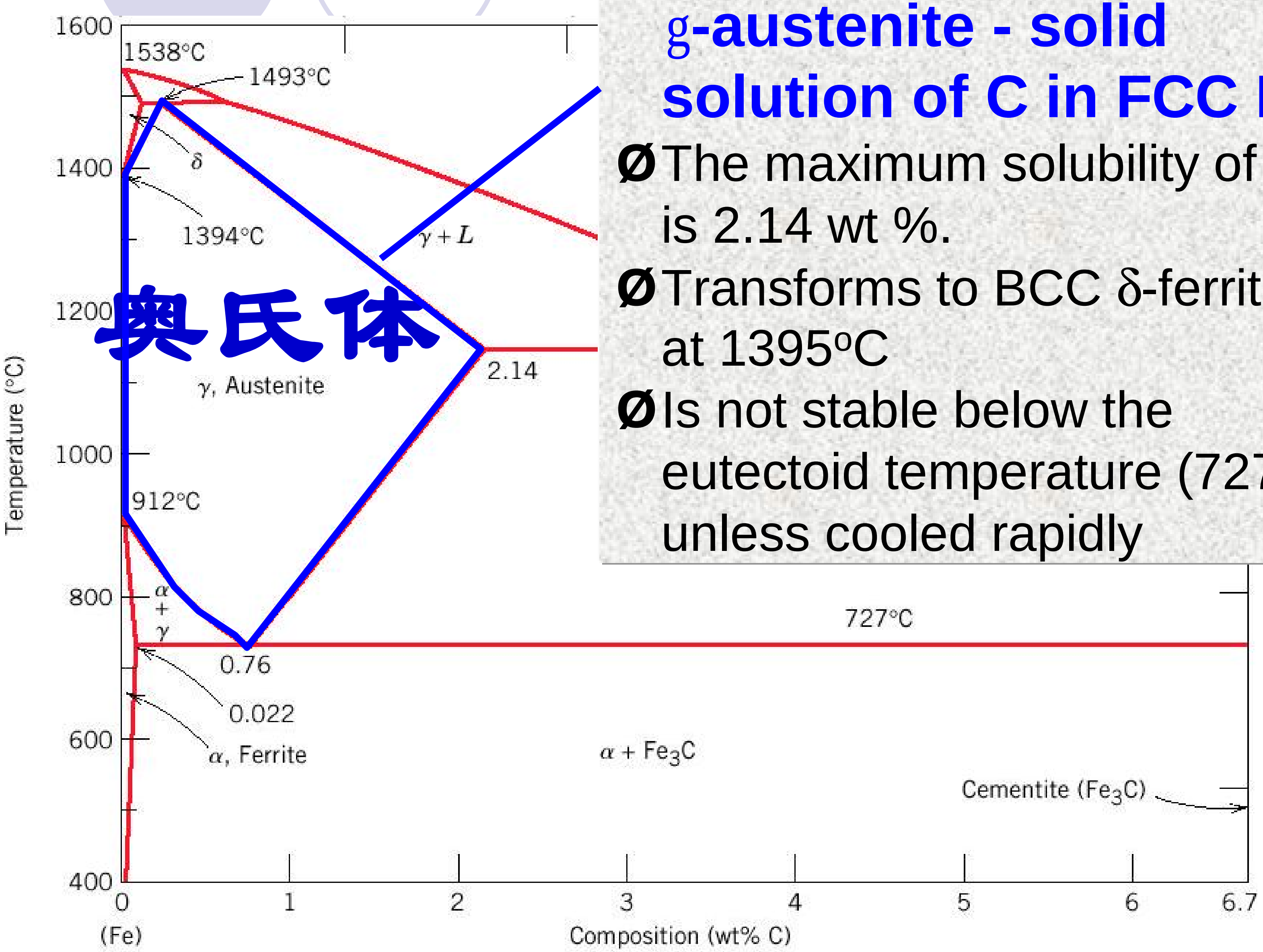
WHAT DO YOU KNOW ABOUT IRON?



γ-austenite - solid solution of C in FCC Fe

- The maximum solubility of C is 2.14 wt %.
- Transforms to BCC δ-ferrite at $1395^{o}C$
- Is not stable below the eutectoid temperature ($727^{o}C$) unless cooled rapidly

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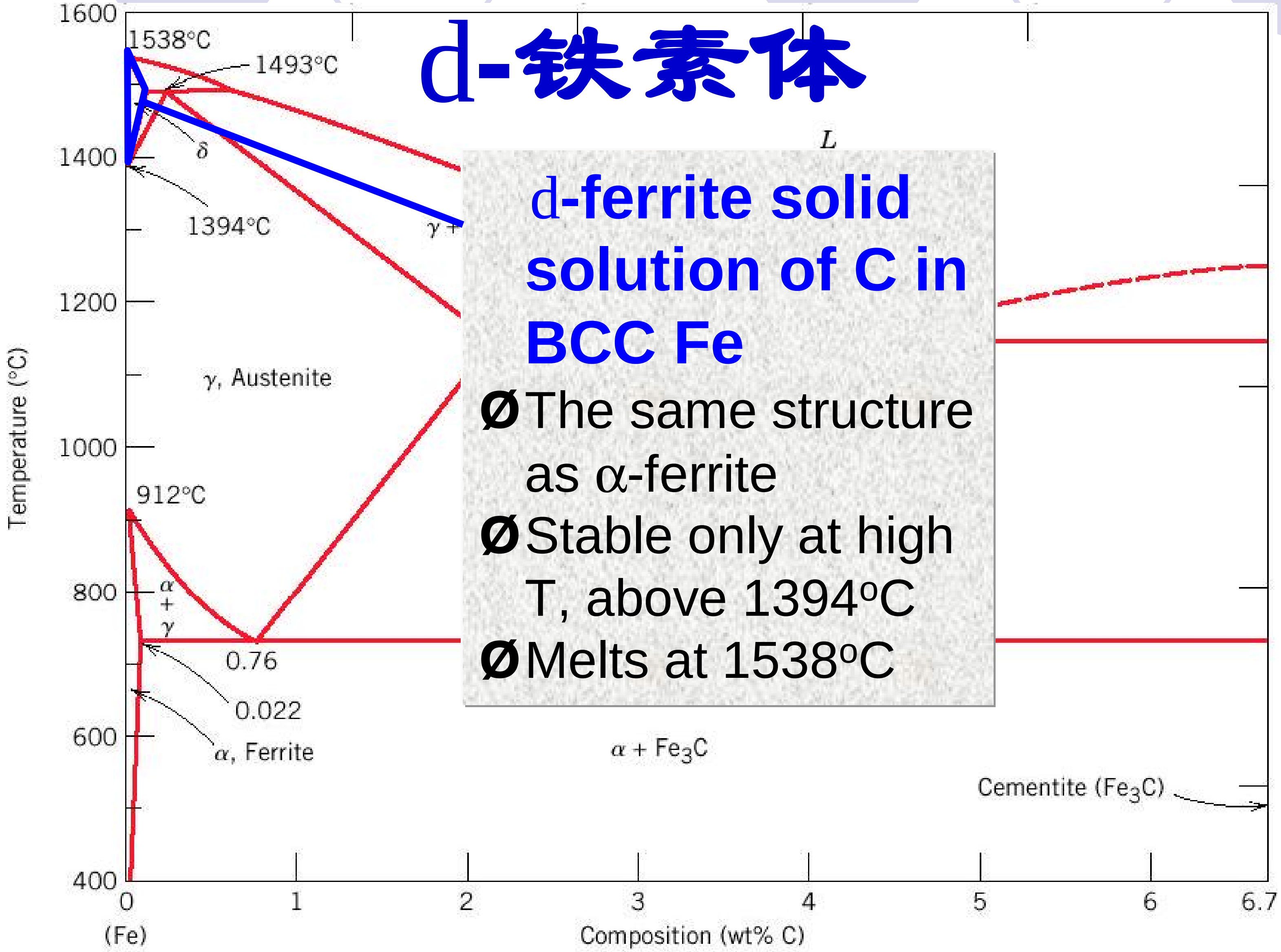
WHAT DO YOU KNOW ABOUT IRON?



d-ferrite solid solution of C in BCC Fe

- The same structure as α-ferrite
- Stable only at high T, above 1394ºC
- Melts at 1538ºC

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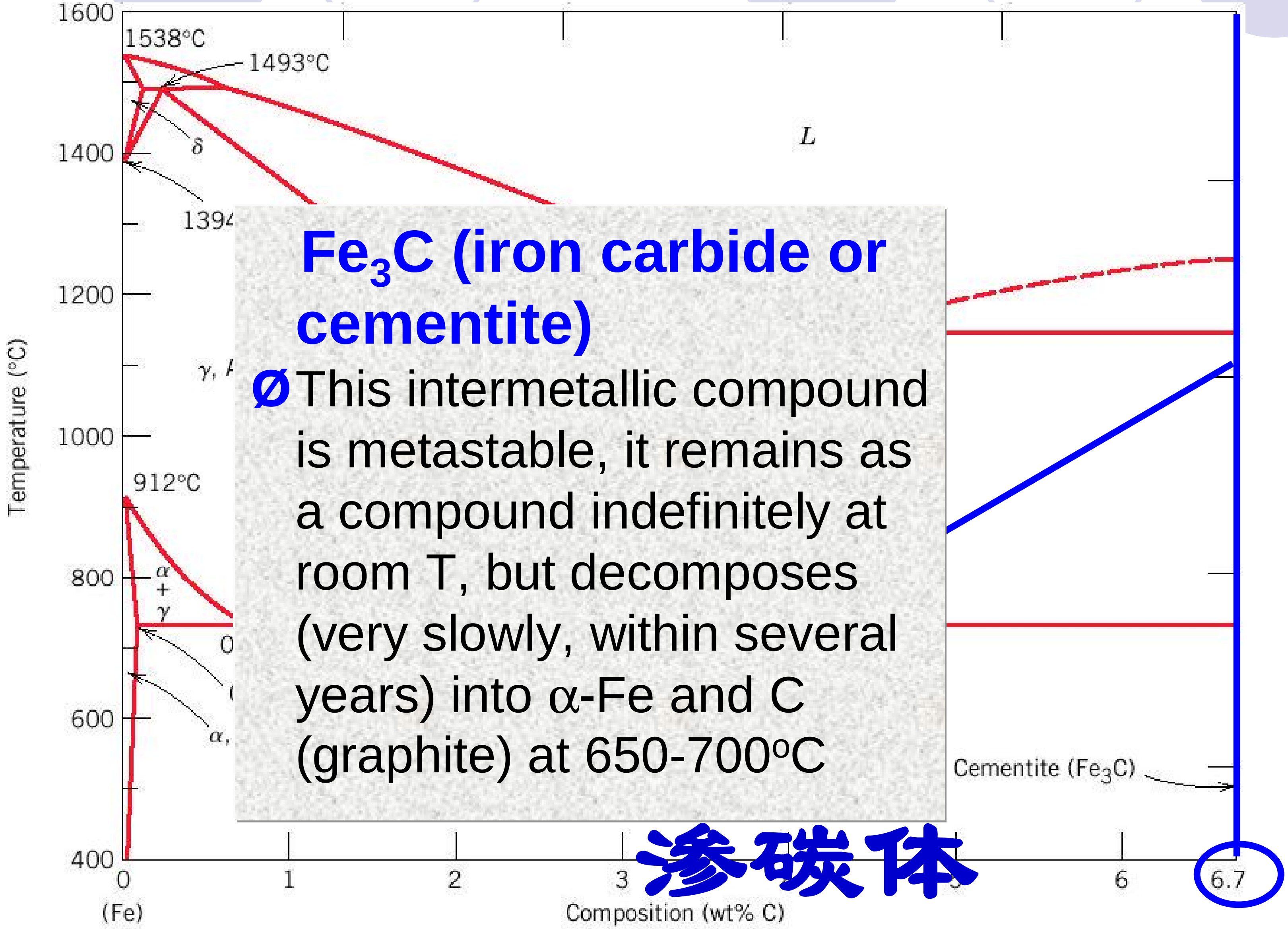
WHAT DO YOU KNOW ABOUT IRON?



Fe_3C (iron carbide or cementite)

- This intermetallic compound is metastable, it remains as a compound indefinitely at room T, but decomposes (very slowly, within several years) into α-Fe and C (graphite) at 650-700^{o}C

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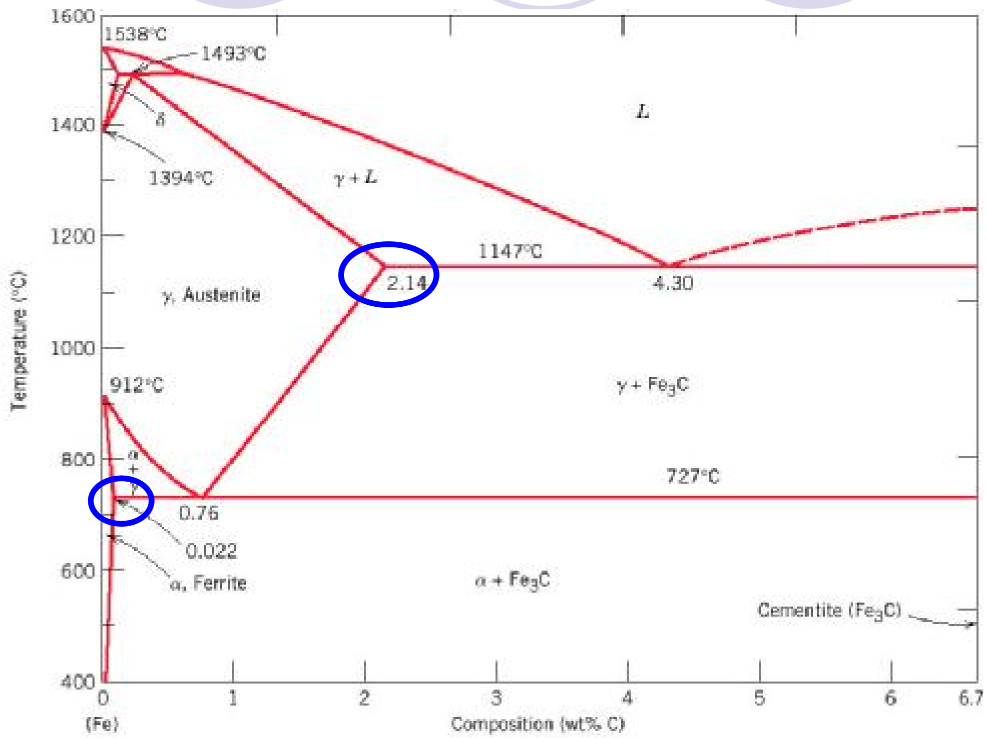
A FEW COMMENTS ABOUT Fe-Fe_3C

- C is an interstitial impurity in Fe. It forms a solid solution with α, γ, δ phases of iron.
- Maximum solubility in BCC α-ferrite is limited (max.0.022 wt% at 727ºC) - BCC has relatively small interstitial positions.



- Maximum solubility in FCC austenite is 2.14 wt% at 1147ºC - FCC has larger interstitial positions

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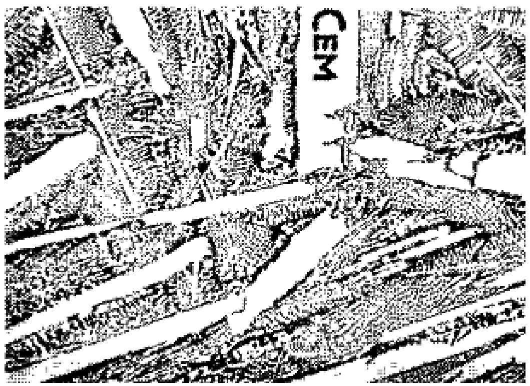
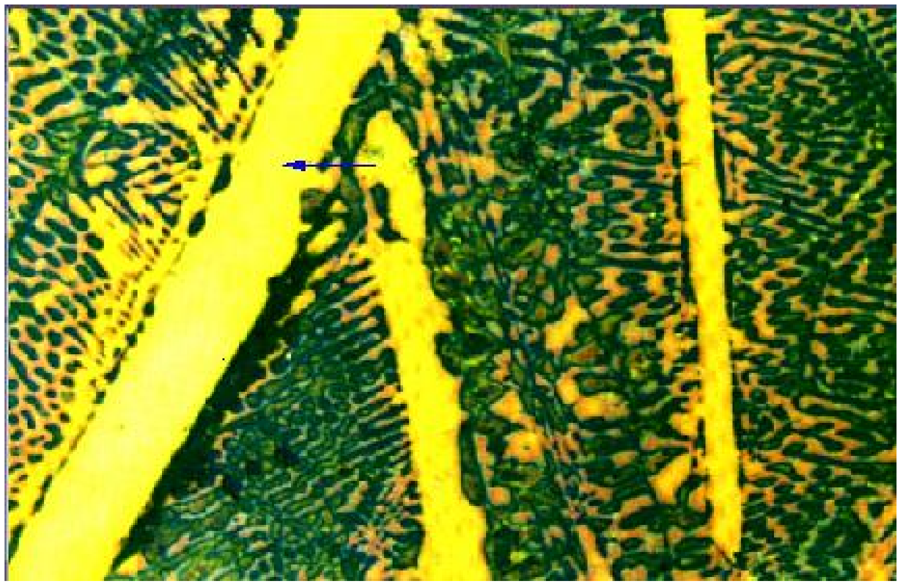
MECHANICAL PROPERTIES

- Cementite is very hard and brittle - can strengthen steels.

- Mechanical properties also depend on the microstructure, that is, how ferrite and cementite are mixed.





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MAGNETIC PROPERTIES

- α -ferrite is magnetic below 768^{o}C,
- Austenite is non-magnetic.

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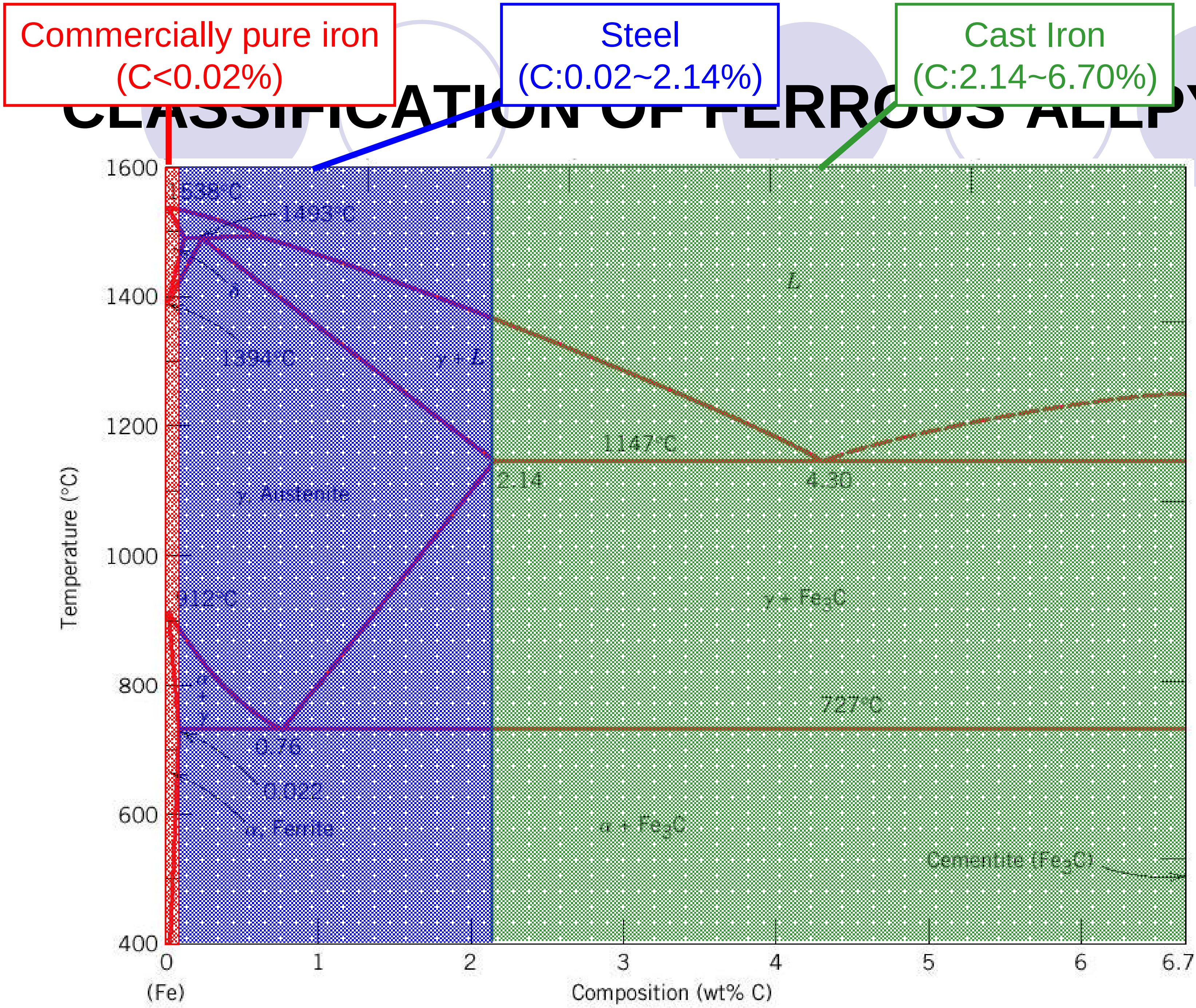
CLASSIFICATION OF FERROUS ALLOYS



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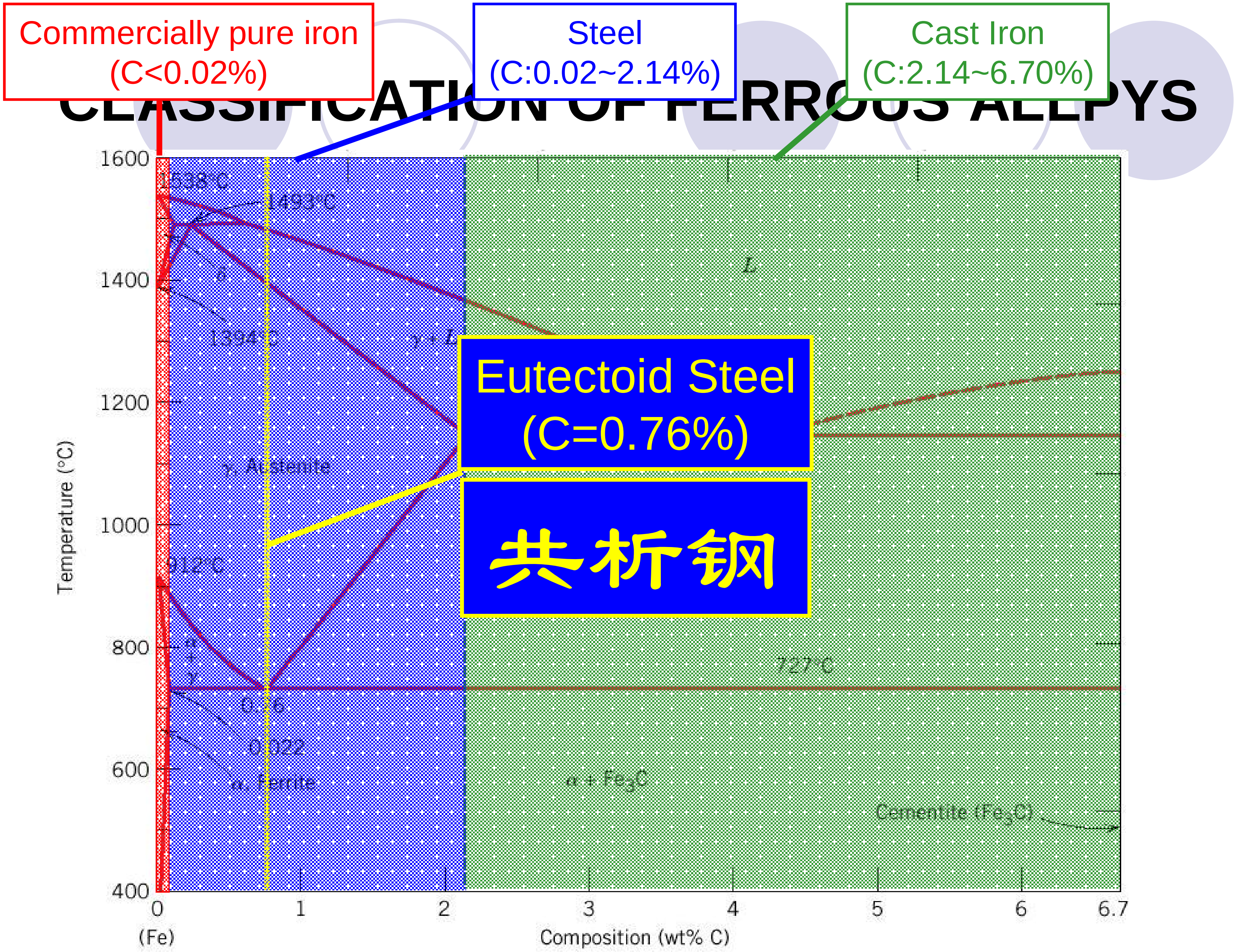
CLASSIFICATION OF FERROUS ALLOYS



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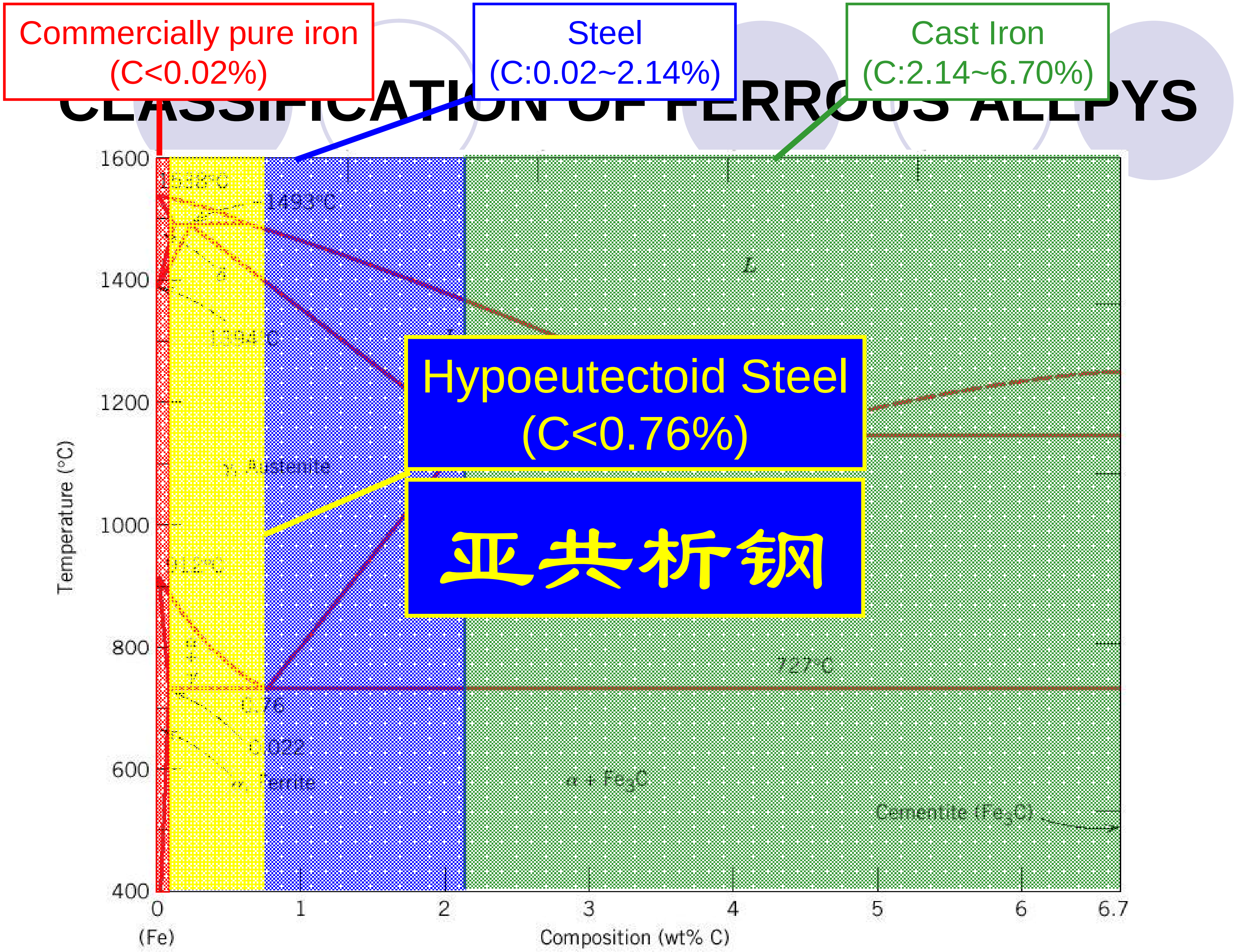
CLASSIFICATION OF FERROUS ALLPYS



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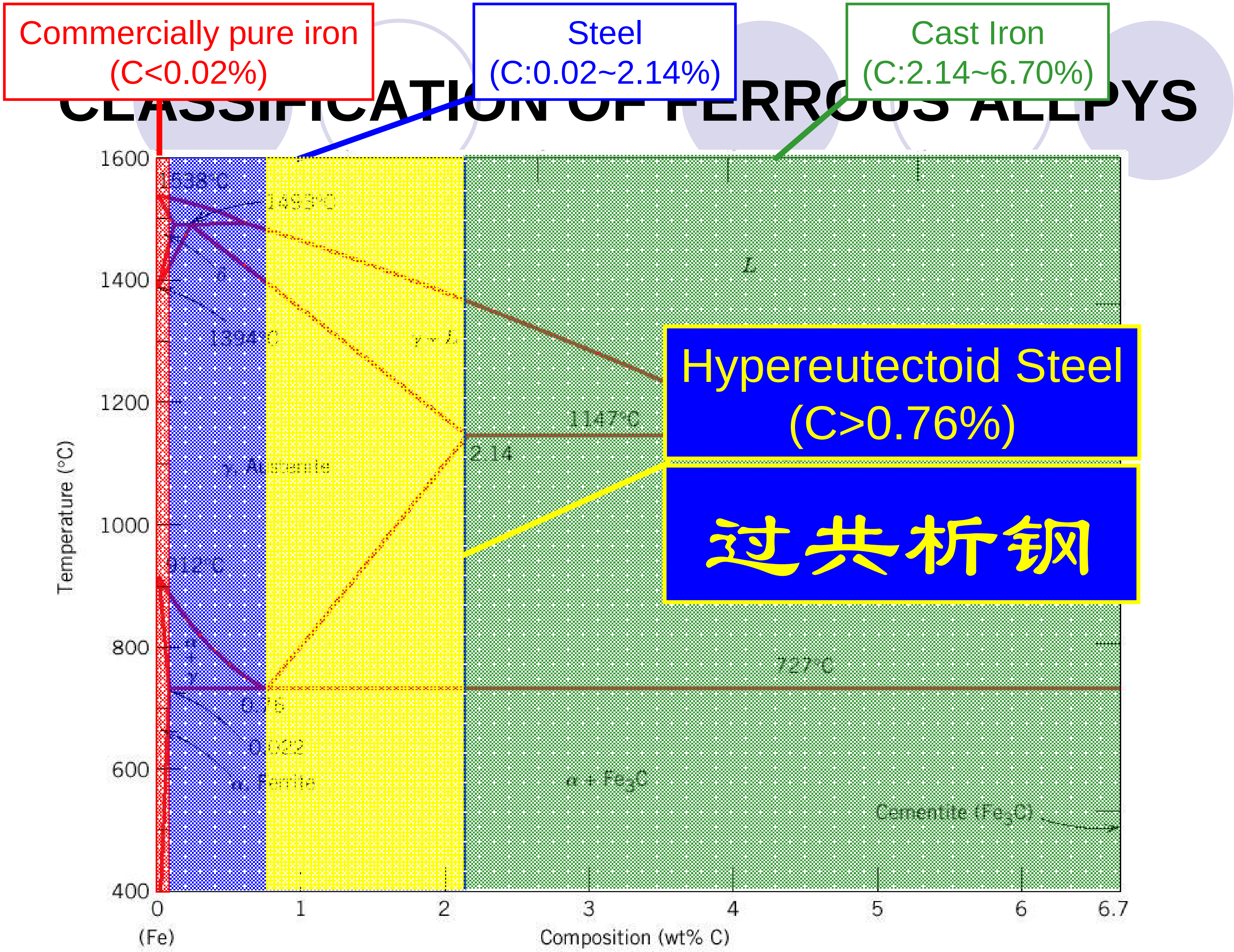
CLASSIFICATION OF FERROUS ALLOYS



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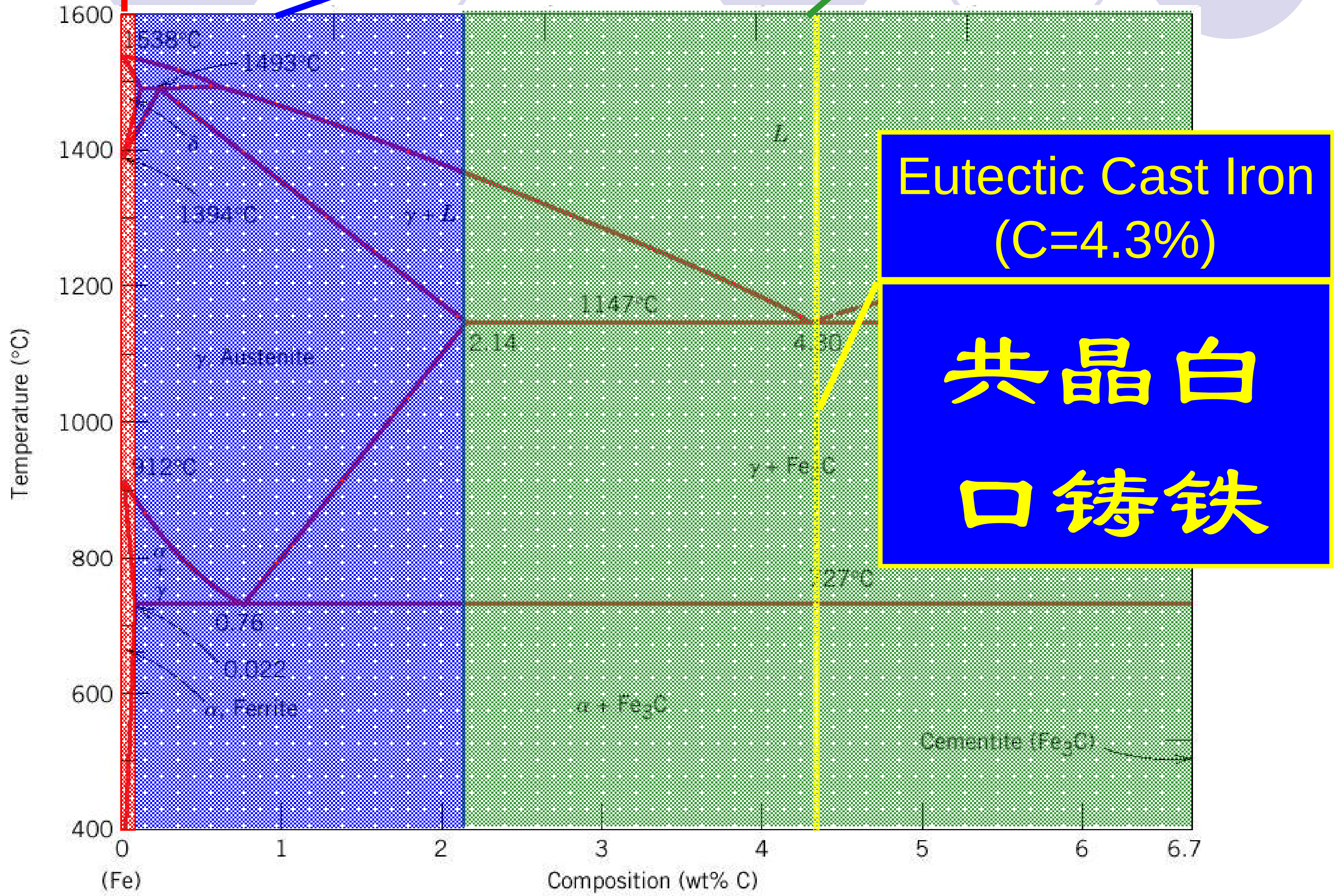
CLASSIFICATION OF FERROUS ALLOYS



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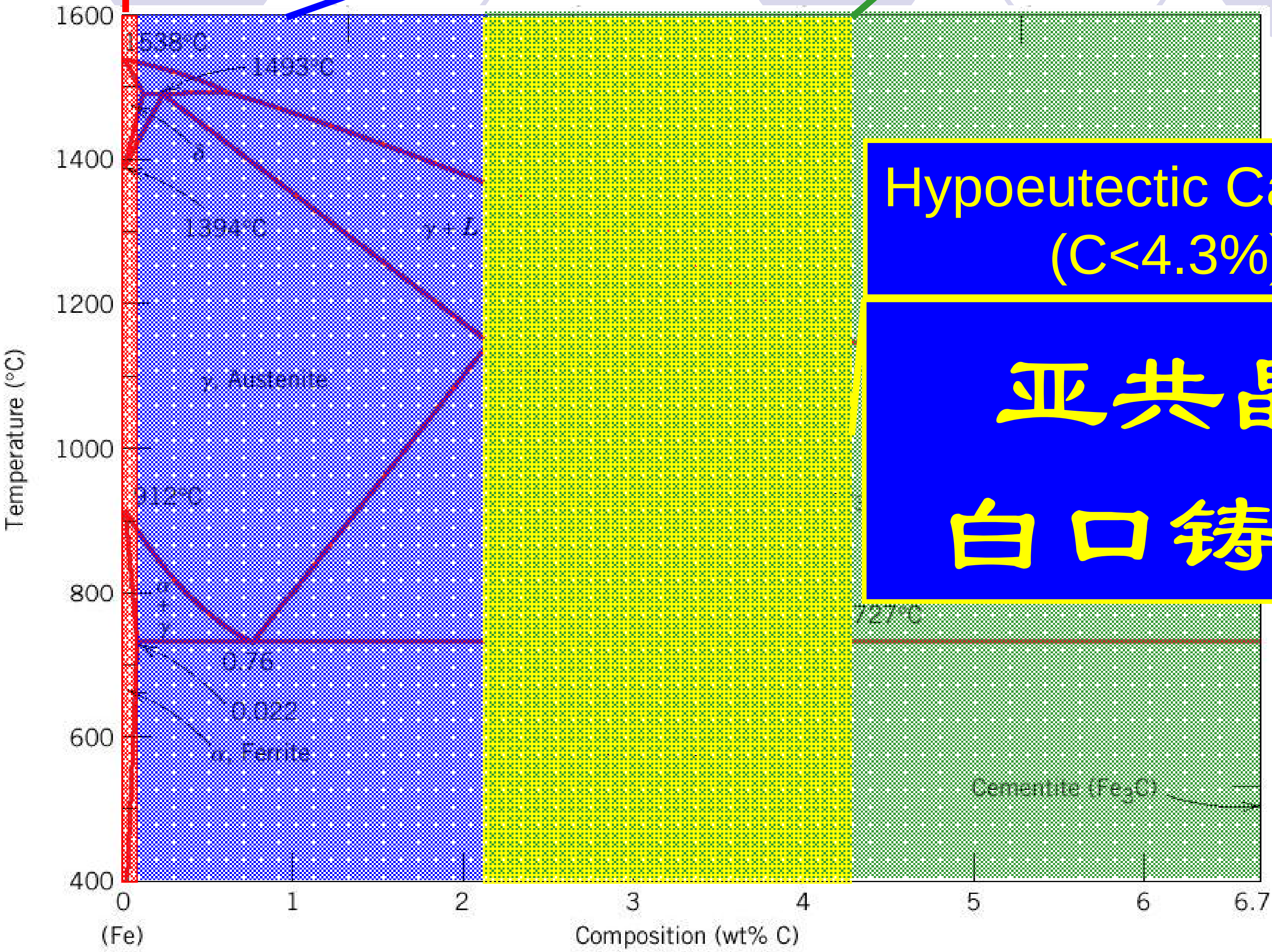
CLASSIFICATION OF FERROUS ALLPYS

Commercially pure iron
(C<0.02%)

Steel
(C:0.02~2.14%)

Cast Iron
(C:2.14~6.70%)



Hypoeutectic Cast Iron
(C<4.3%)

亚共晶
白口铸铁

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CLASSIFICATION OF FERROUS ALLPYS

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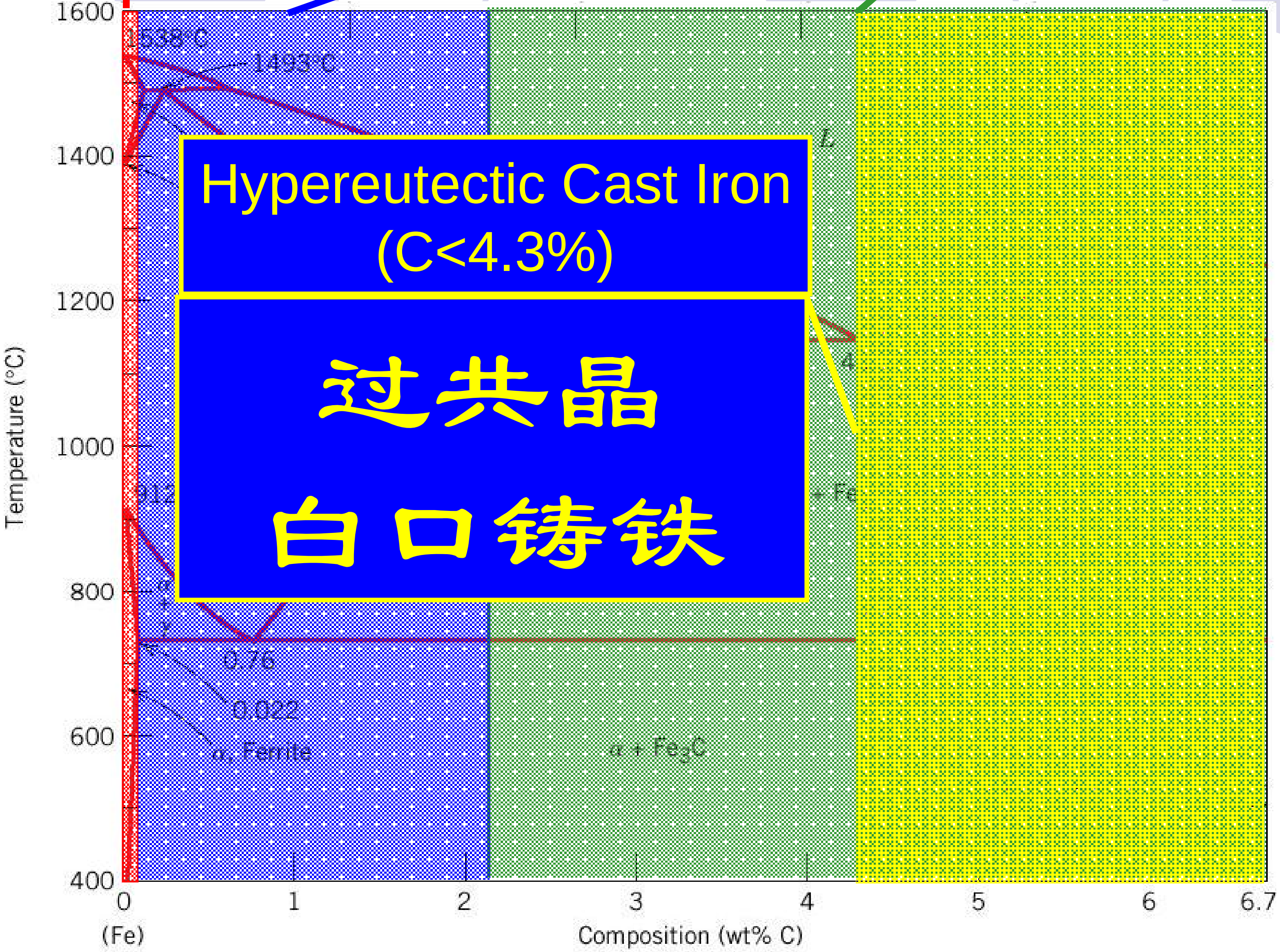

Hypereutectic Cast Iron
(C<4.3%)

过共晶
白口铸铁

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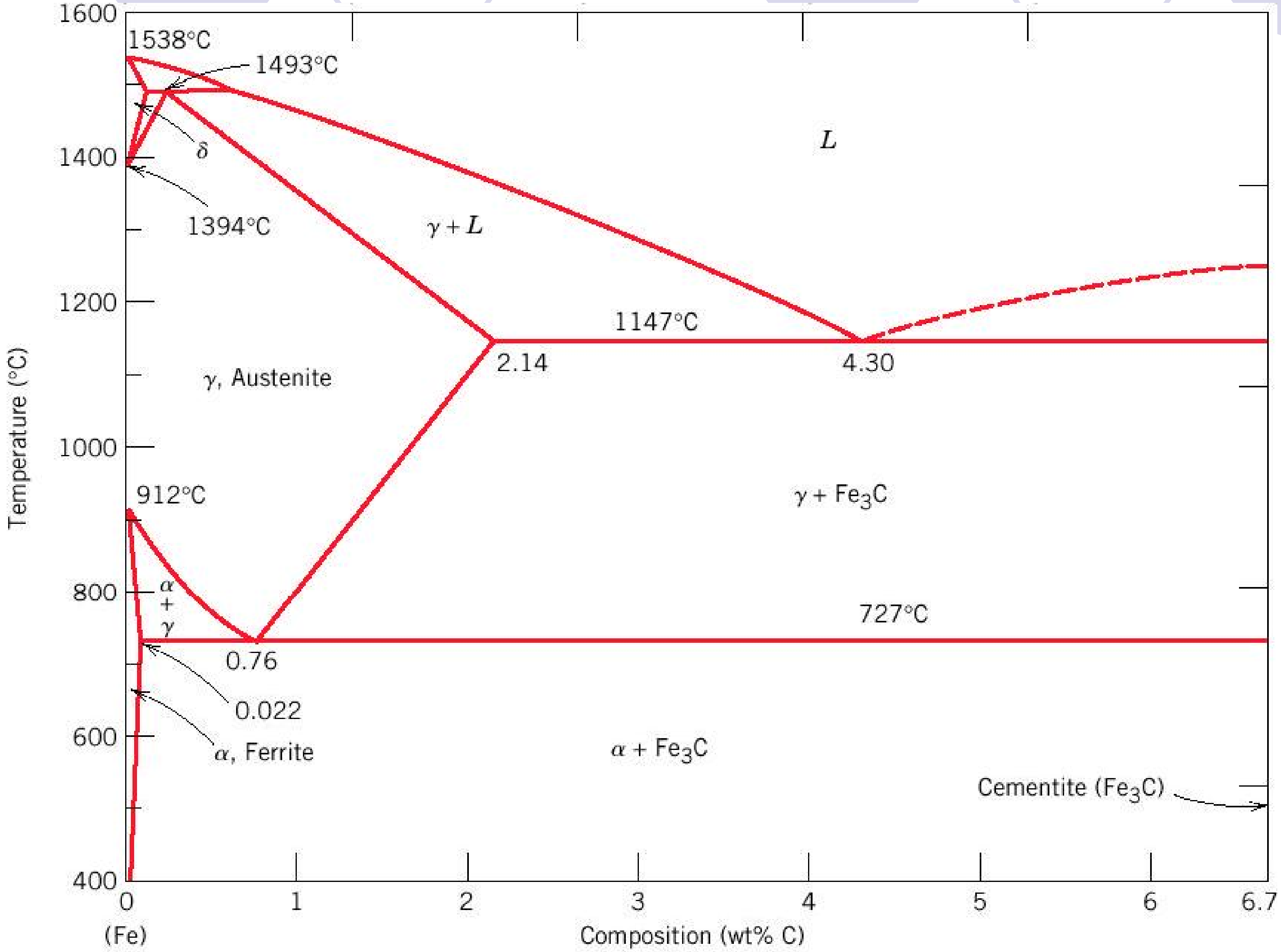
IMPORTANT LINES AND REACTIONS



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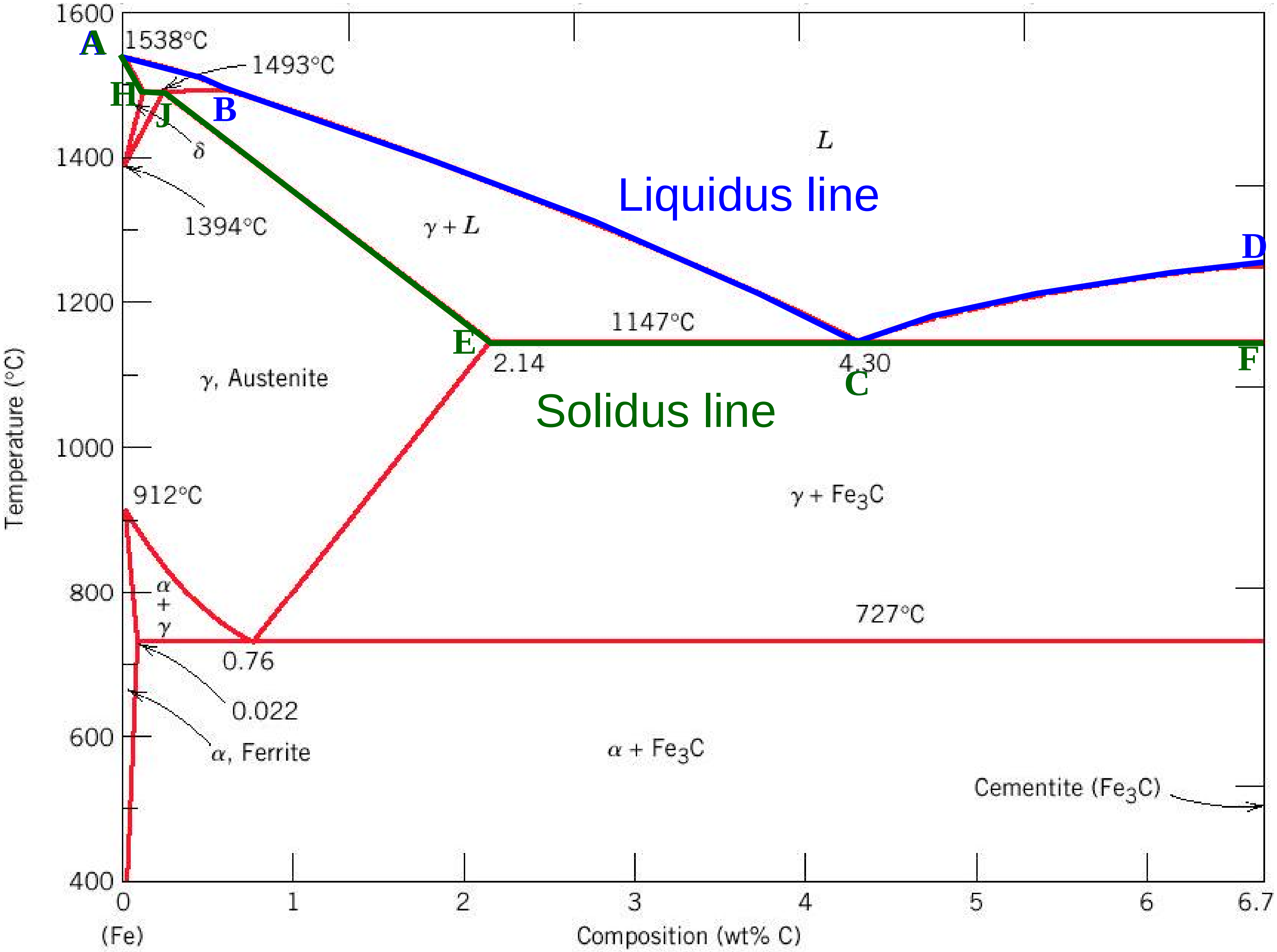

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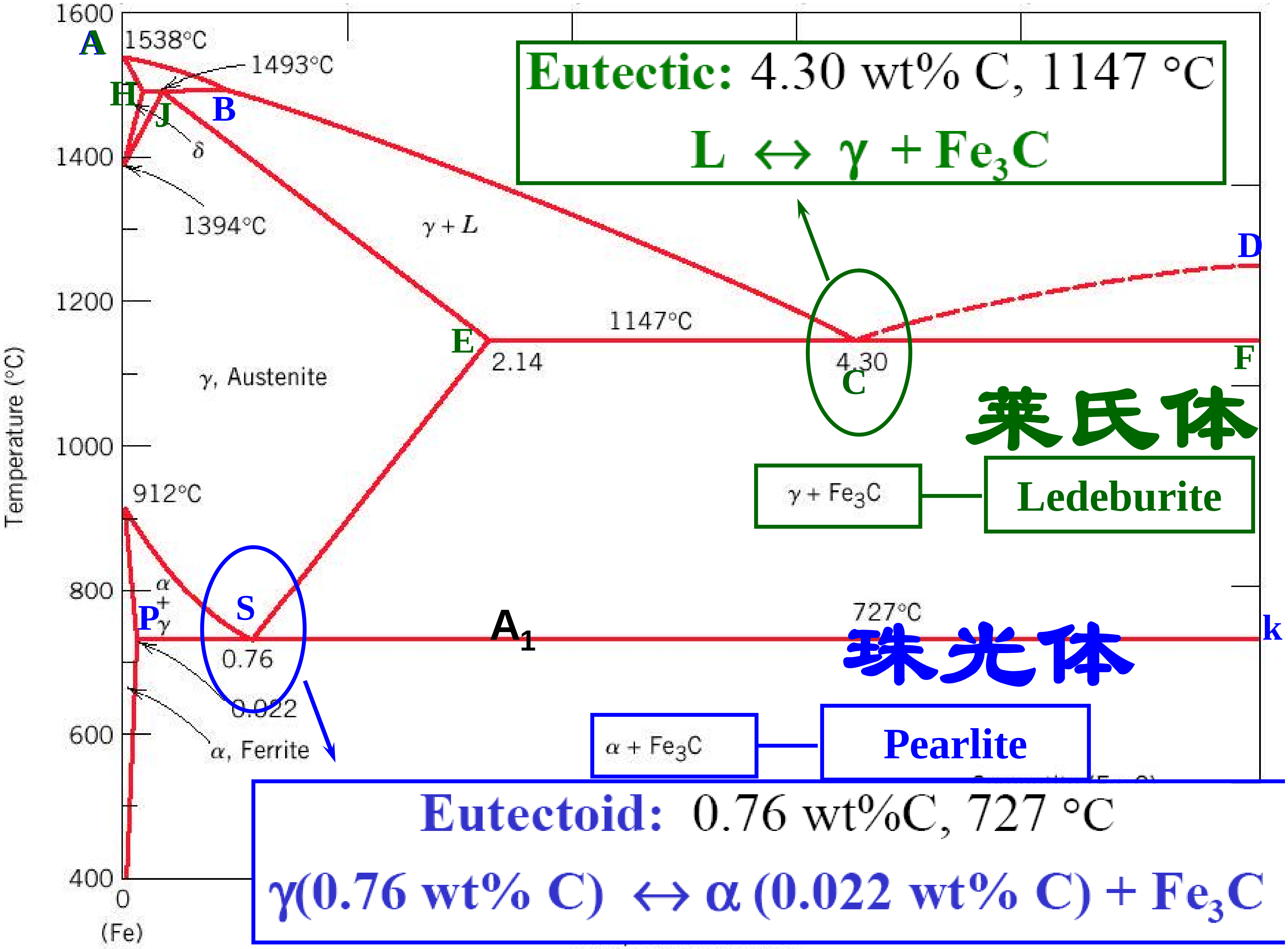

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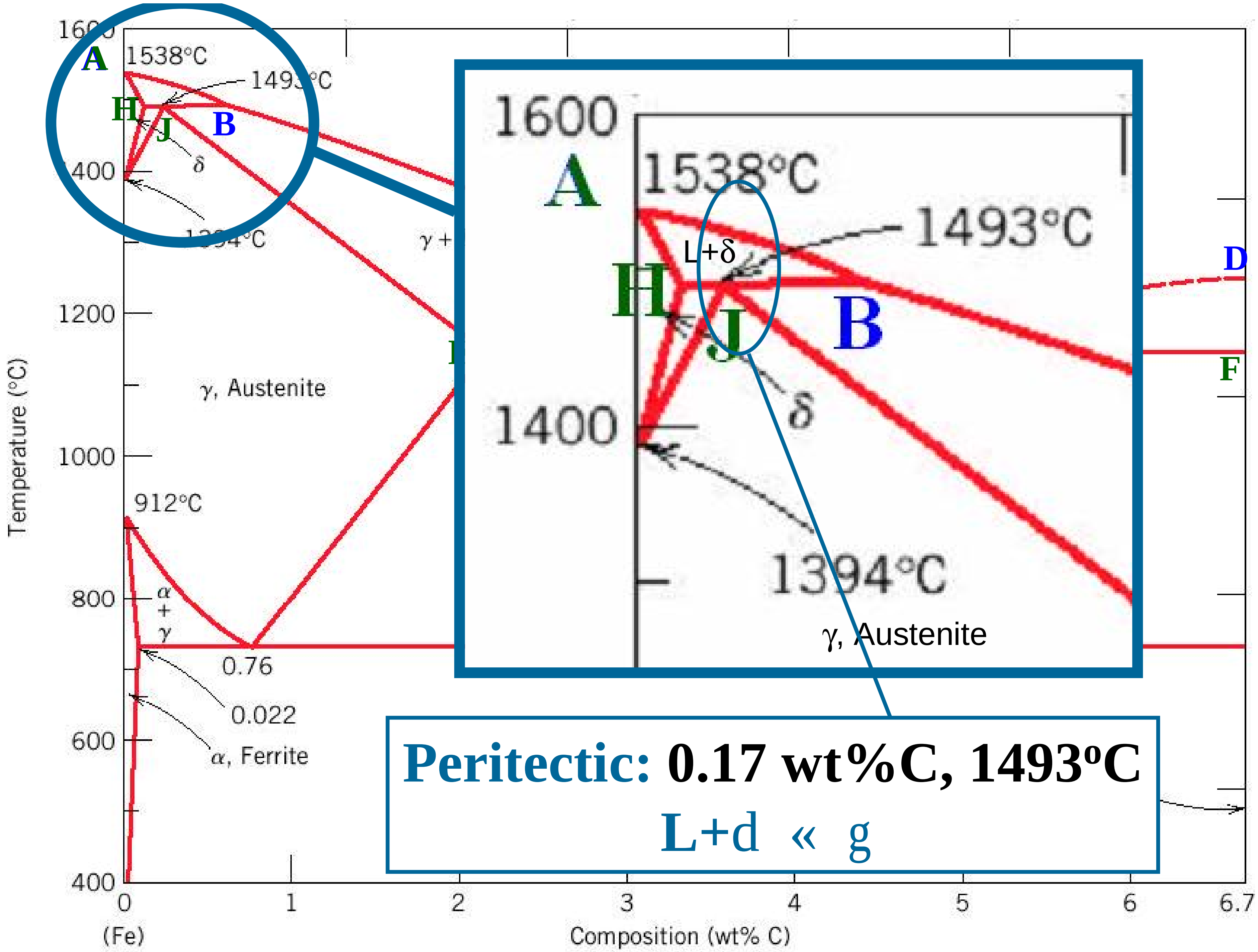

Peritectic: 0.17 wt%C, 1493ºC

L+d « g

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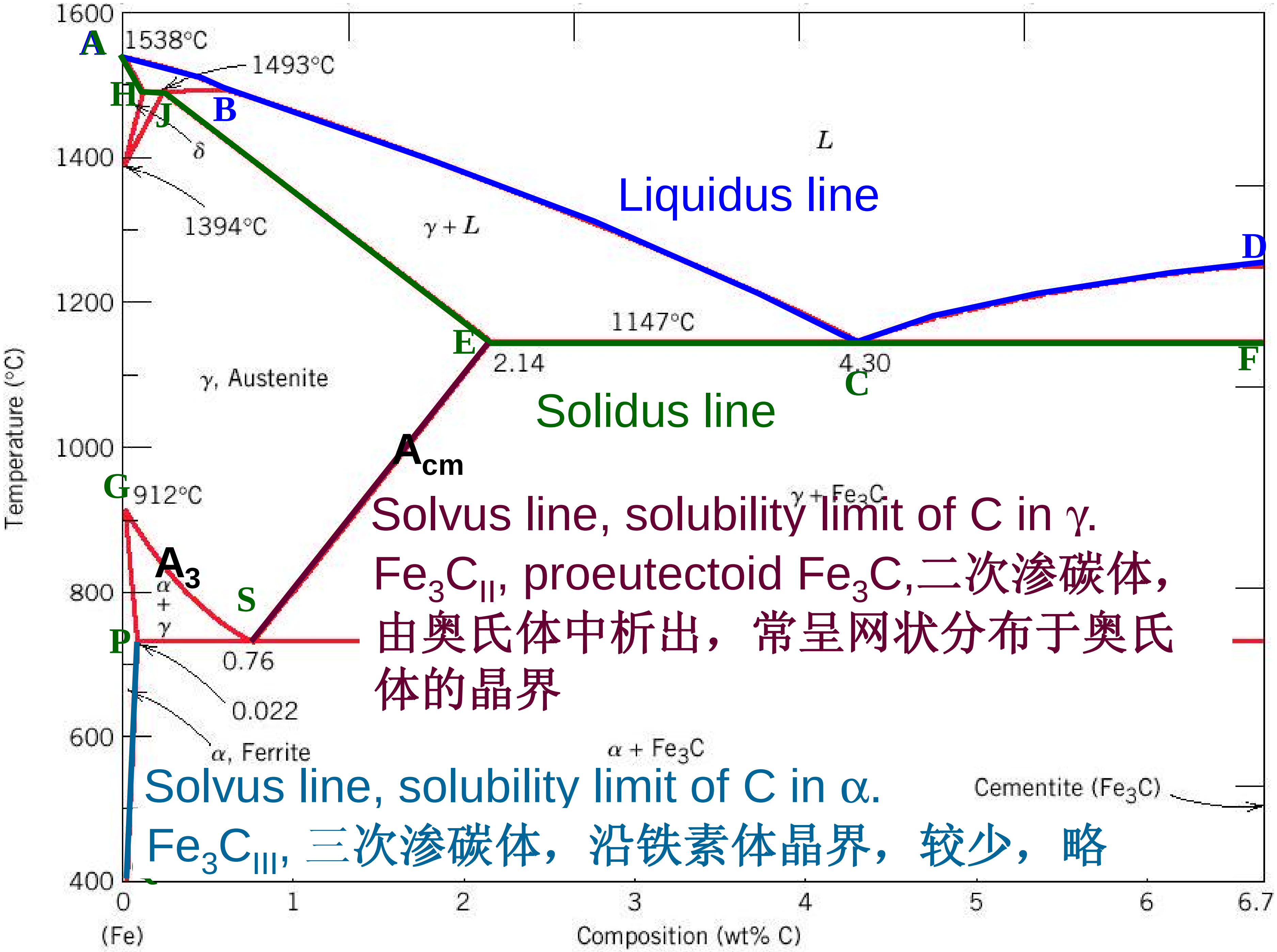

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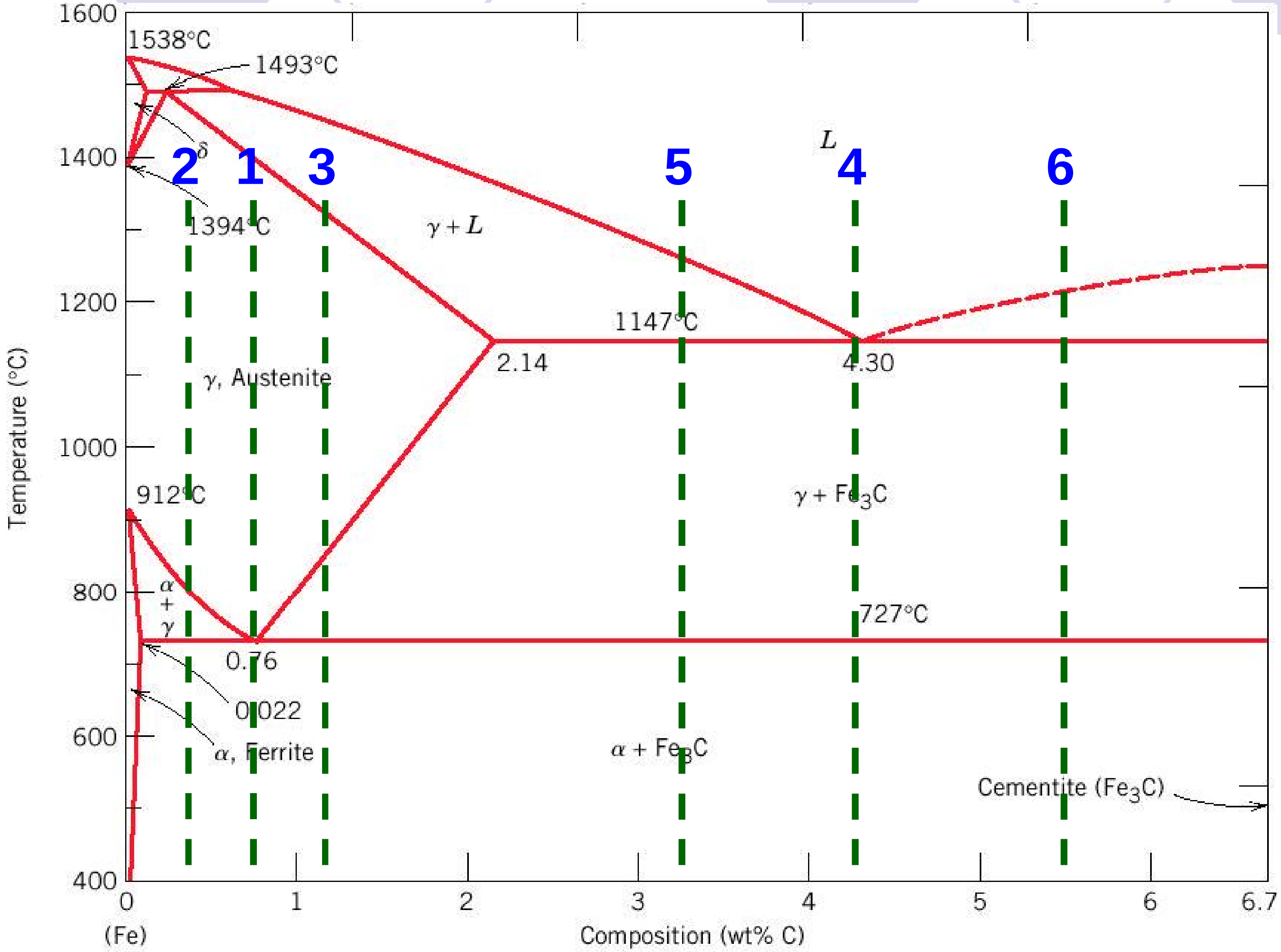
EQUILIBRIUM MICROSTRUCTURE



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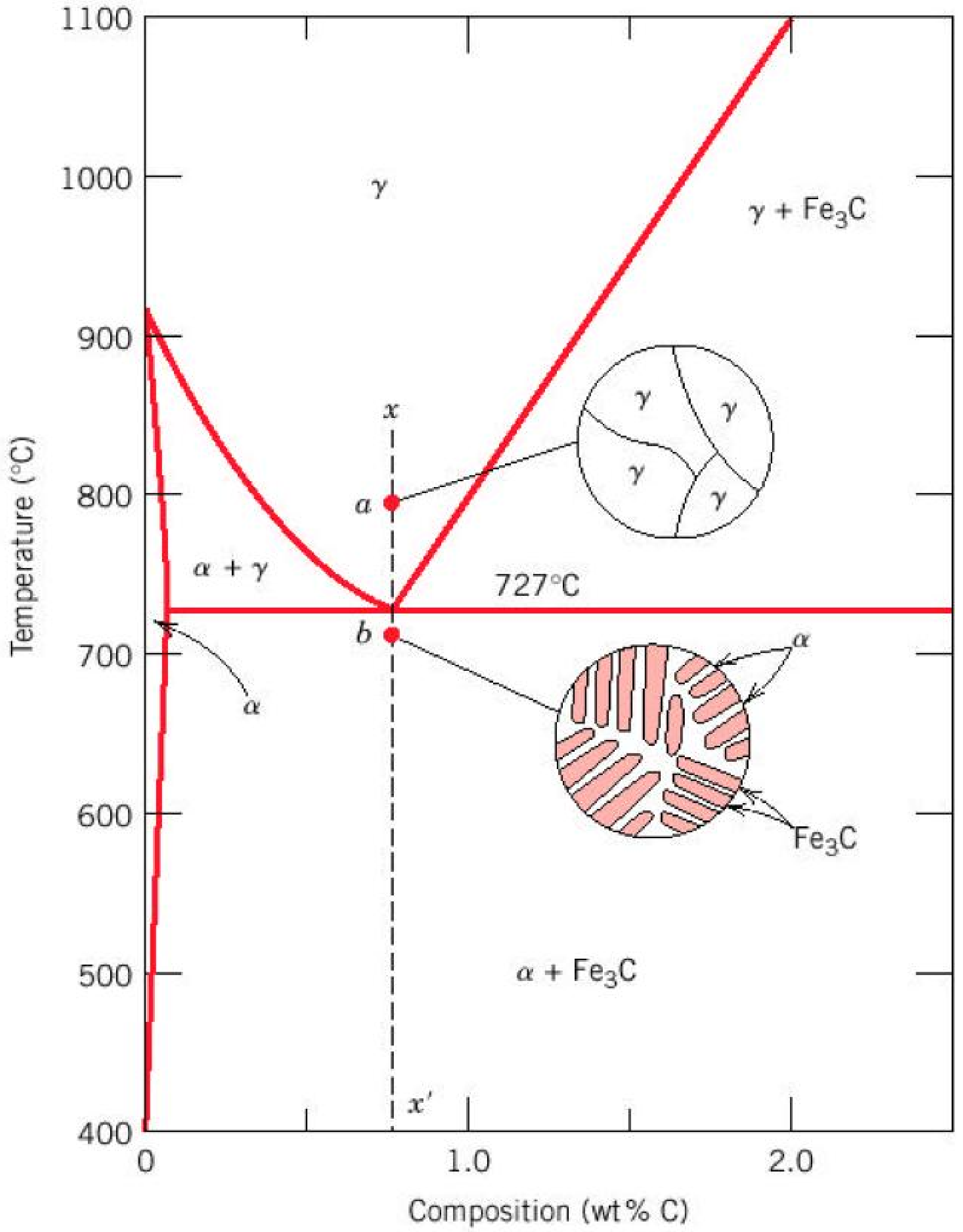
EUTECTOID

- When alloy of eutectoid composition (0.76 wt % C) is cooled slowly it forms pearlite, a lamellar or layered structure of two phases: α-ferrite and cementite (Fe_3C)



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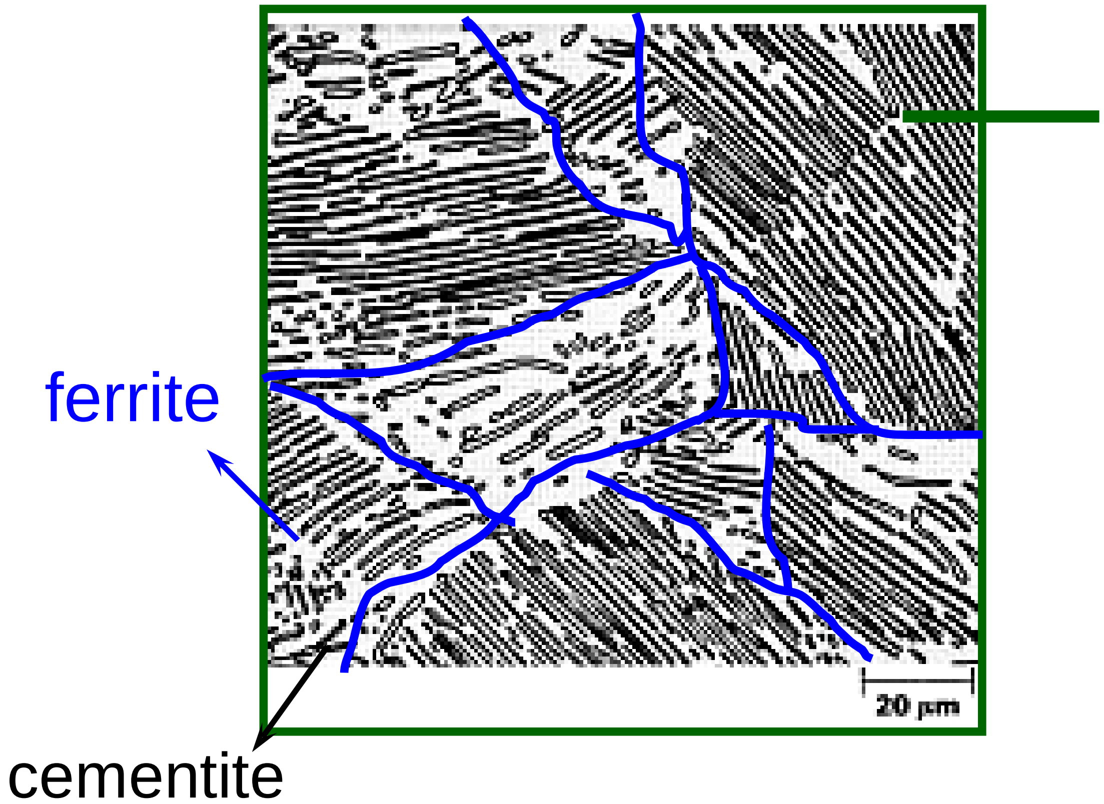
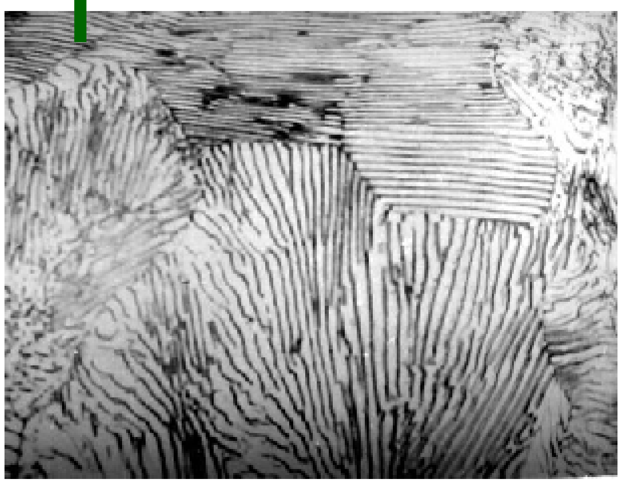
Pearlite

- The pearlite exists as grains, often termed "colonies"; within each colony the layers are oriented in the same direction, which varies from one colony to another.





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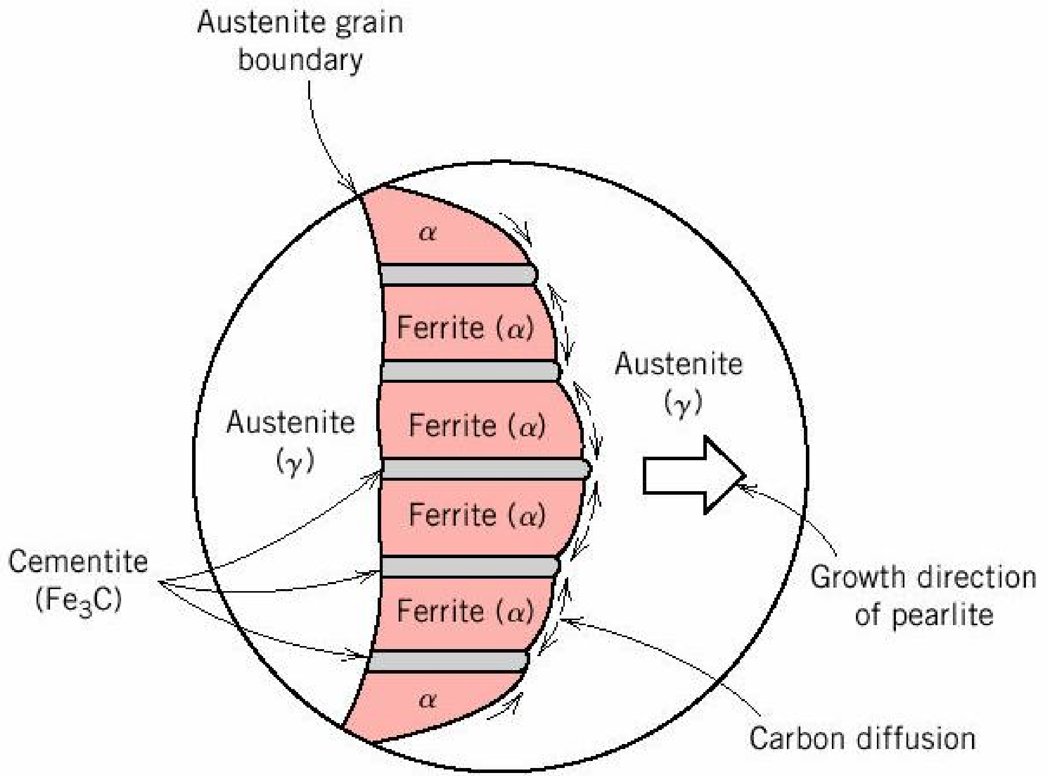
Pearlite

- The layers of alternating phases in pearlite are formed for the same reason as layered structure of eutectic structures: redistribution C atoms between ferrite (0.022 wt%) and cementite (6.7 wt%) by atomic diffusion.
- Mechanically, pearlite has properties intermediate to soft, ductile ferrite and hard, brittle cementite.



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HYPOEUTECTOID

γ

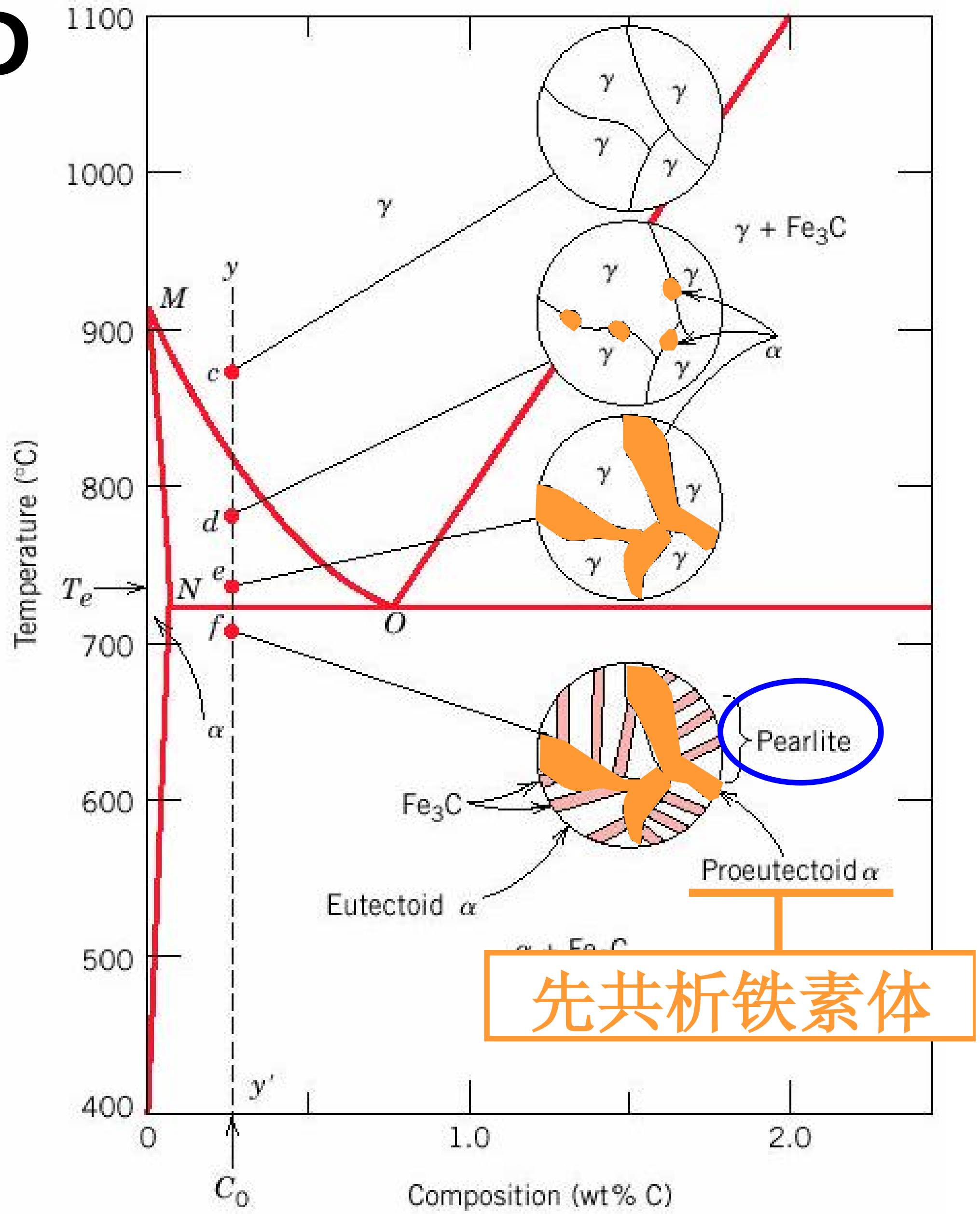
$\downarrow$

$\alpha + \gamma$

$\downarrow$

$\alpha + Fe_3C$

- In α+γ region, the composition of α phase changes along MN, the composition of γ phase changes along MO…



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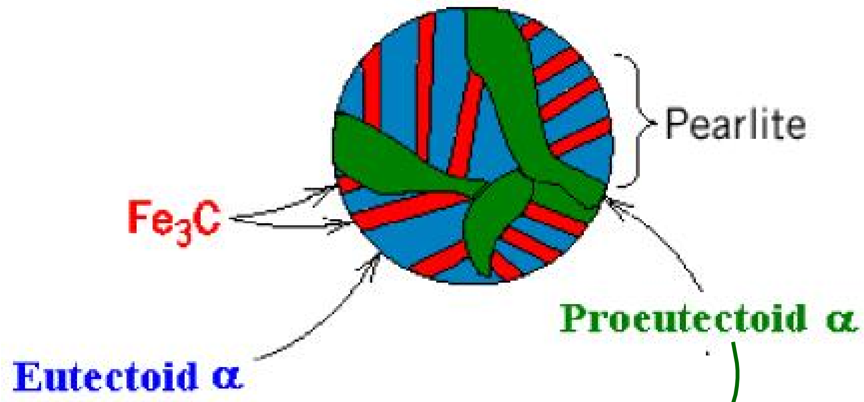
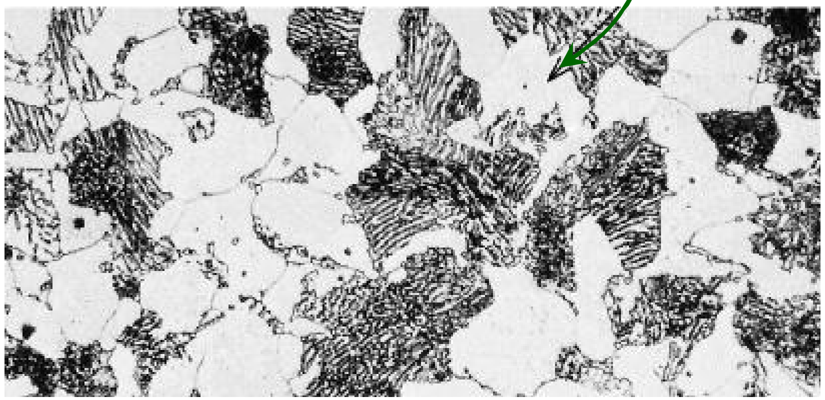
HYPOEUTECTOID

- Hypoeutectoid alloys contain proeutectoid ferrite (formed above the eutectoid temperature) plus the eutectoid pearlite that contain eutectoid ferrite and cementite.





Microstructure of a 0.38wt% steel.
Courtesy Republic Steel Corp.

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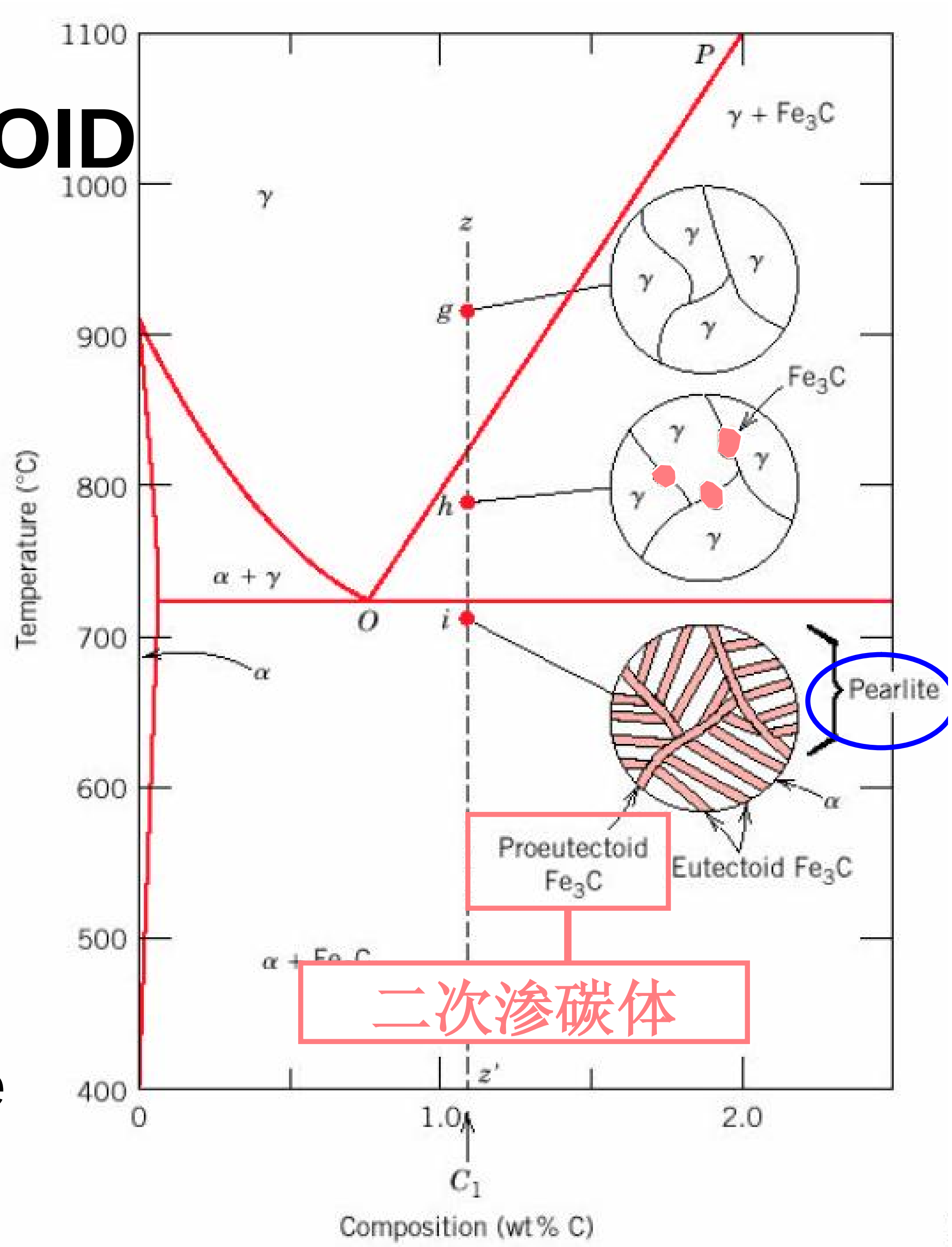
HYPEREUTECTOID

$$\gamma \downarrow \gamma + Fe_3C \downarrow \alpha + Fe_3C$$

- In γ+Fe_3C region, the composition of cementite phase remains constant, the composition of γ phase changes along PO…



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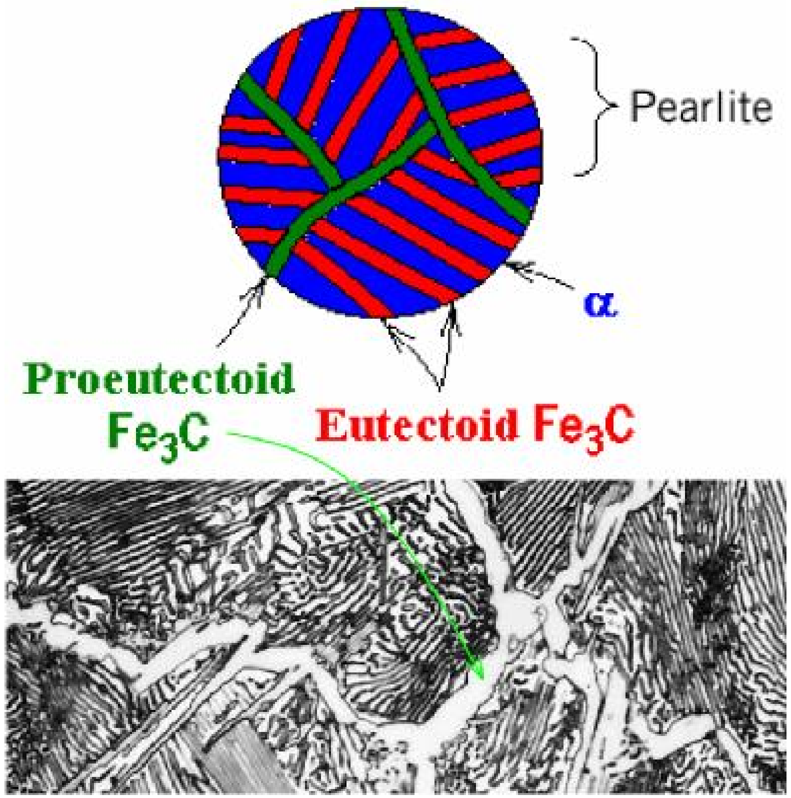
HYPEREUTECTOID

- Hypereutectoid alloys contain proeutectoid cementite (formed above the eutectoid temperature) plus pearlite that contain eutectoid ferrite and cementite.



Microstructure of a 1.4wt% steel.
Courtesy U.S. Steel Corp.

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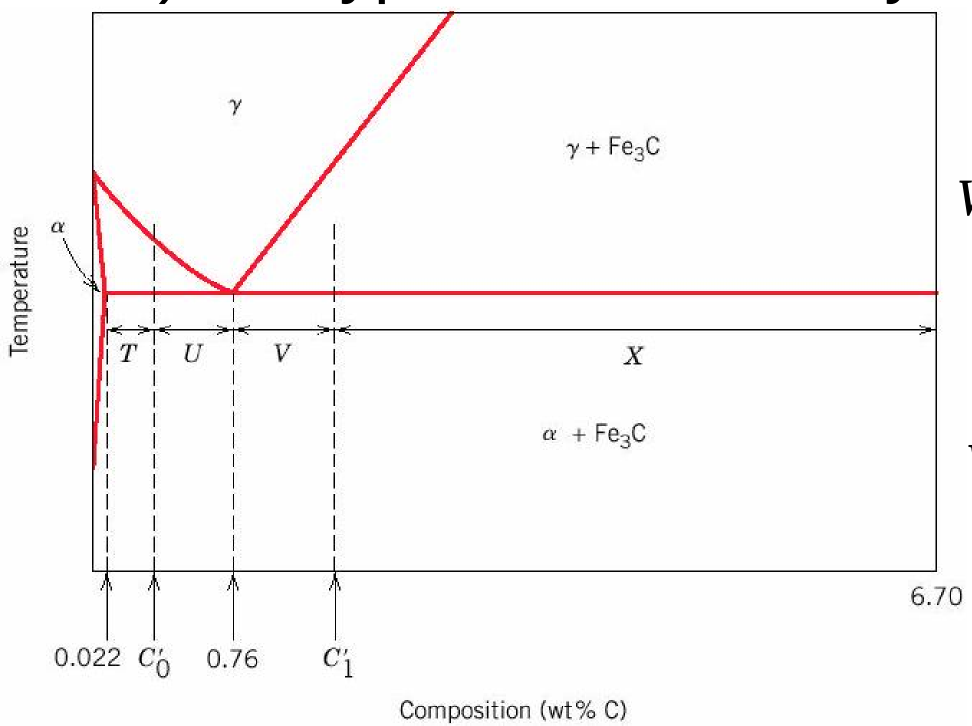
CALCULATION OF PHASE AMOUNT

- Application of the lever rule with tie line that extends from the eutectoid composition (0.75 wt% C) to α–(α+ Fe_3C) boundary (0.022 wt% C) for hypoeutectoid alloys and to (α + Fe_3C) – Fe_3C boundary (6.7 wt% C) for hypereutectoid alloys.



Fraction of pearlite:

$$W_p = \frac{T}{T+U} = \frac{C_0^{'} - 0.022}{0.76 - 0.022} = \frac{C_0^{'} - 0.022}{0.74}$$

Fraction of proeutectoid α:

$$W_{a^{'}} = \frac{U}{T+U} = \frac{0.76 - C_0^{'}}{0.76 - 0.022} = \frac{0.76 - C_0^{'}}{0.74}$$

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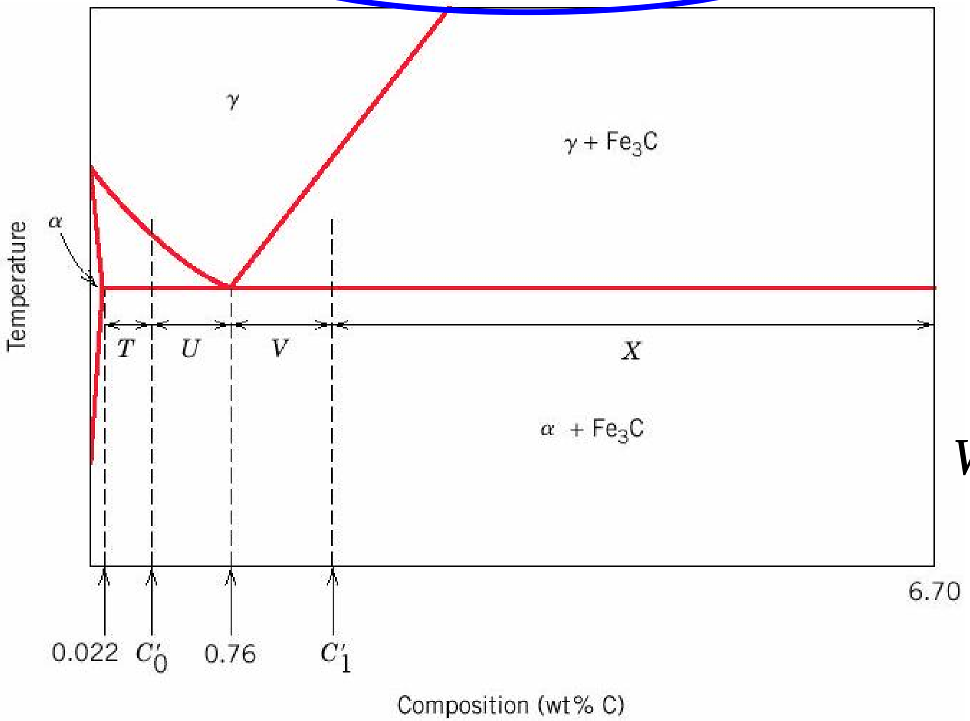
CALCULATION OF PHASE AMOUNT

- Application of the lever rule with tie line that extends from the eutectoid composition (0.75 wt% C) to α–(α+ Fe_3C) boundary (0.022 wt% C) for hypoeutectoid alloys and to (α + Fe_3C) – Fe_3C boundary (6.7 wt% C) for hypereutectoid alloys.



Fraction of pearlite:

$$W_p = \frac{X}{V+X} = \frac{6.7 - C_1'}{6.7 - 0.76} = \frac{6.7 - C_1'}{5.94}$$

Fraction of proeutectoid cementite:

$$W_{Fe_3C'} = \frac{V}{V+X} = \frac{C_1' - 0.76}{6.70 - 0.76} = \frac{C_1' - 0.76}{5.94}$$

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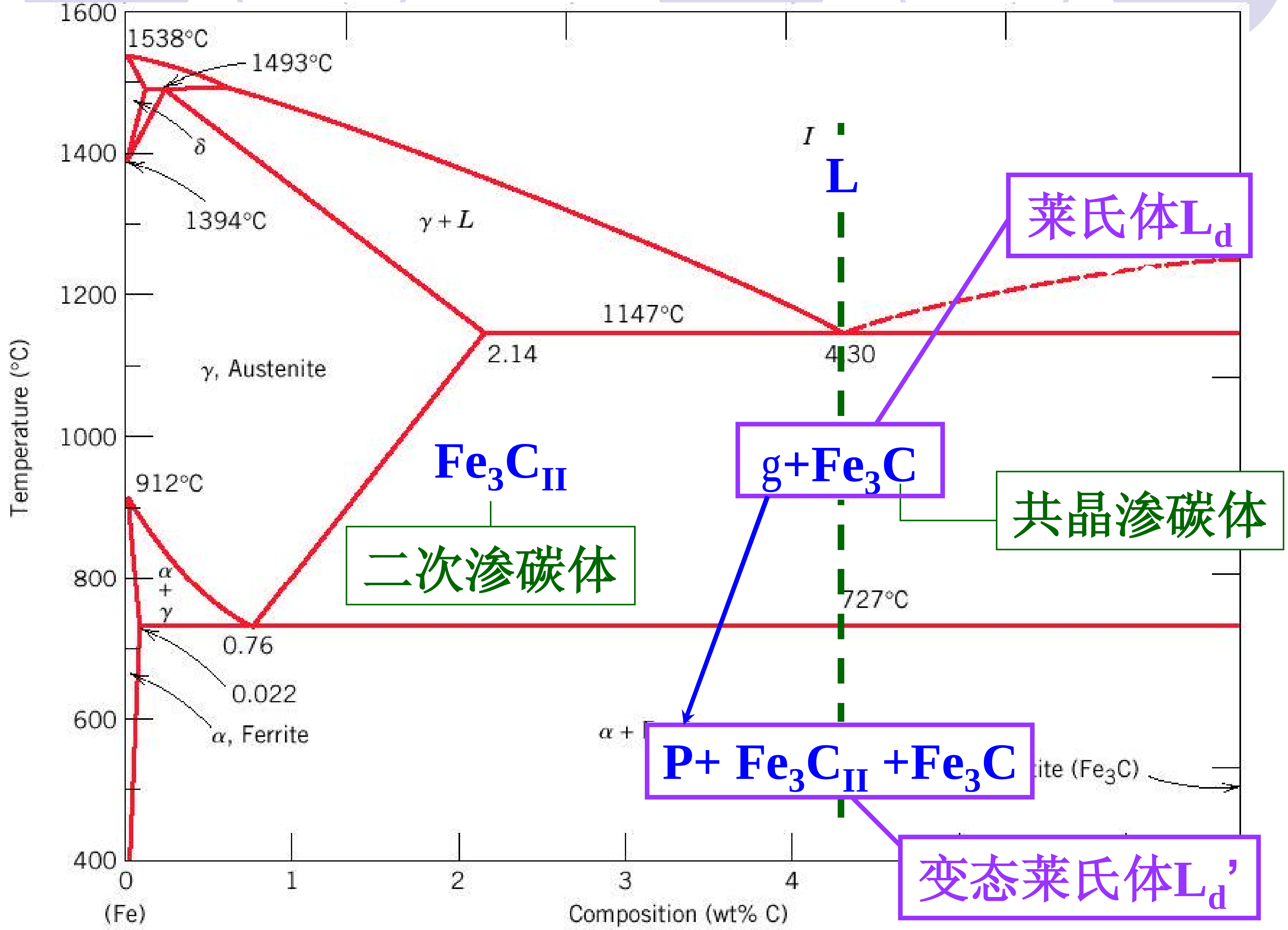
EUTECTIC



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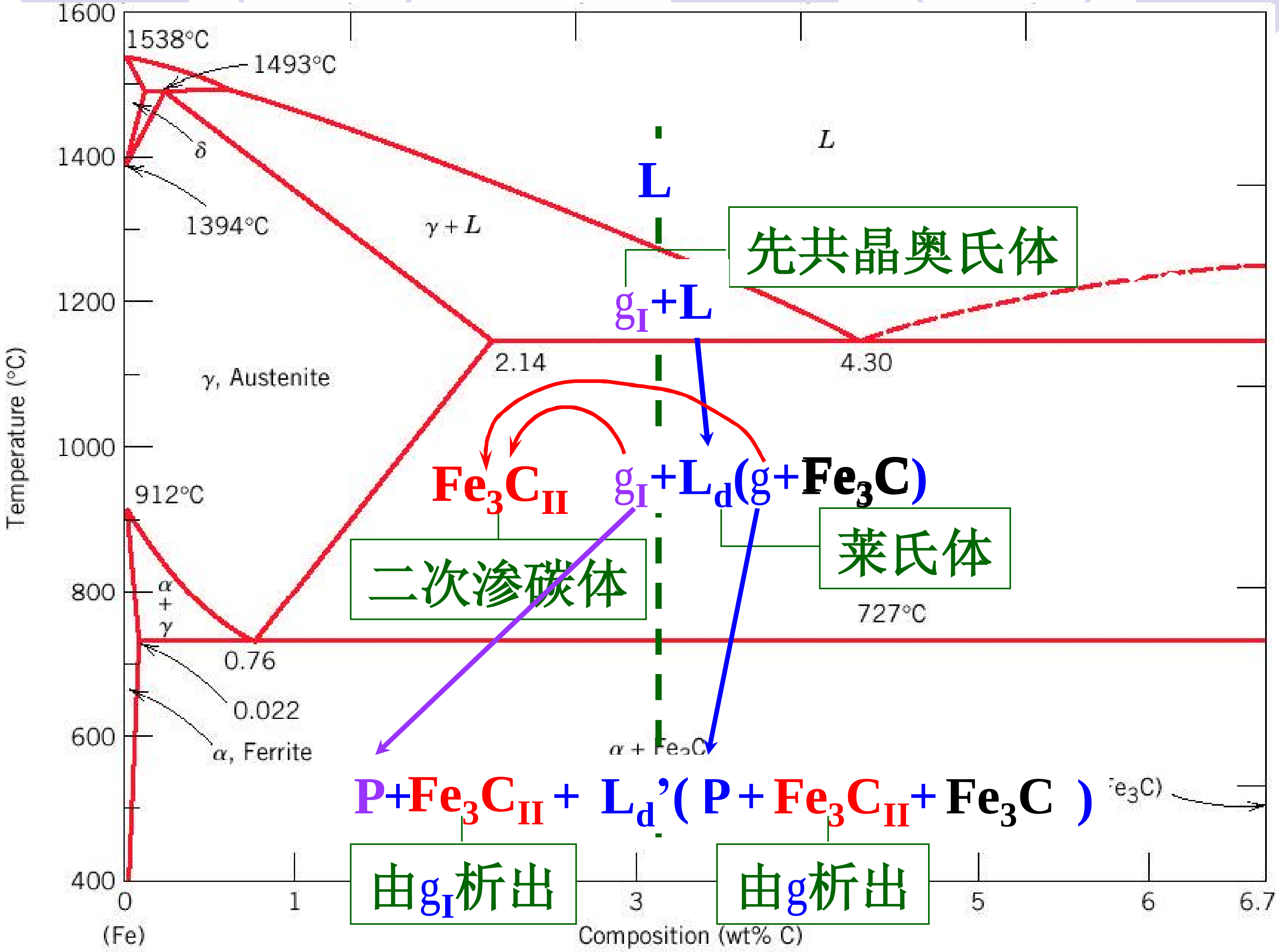
HYPOEUTECTIC



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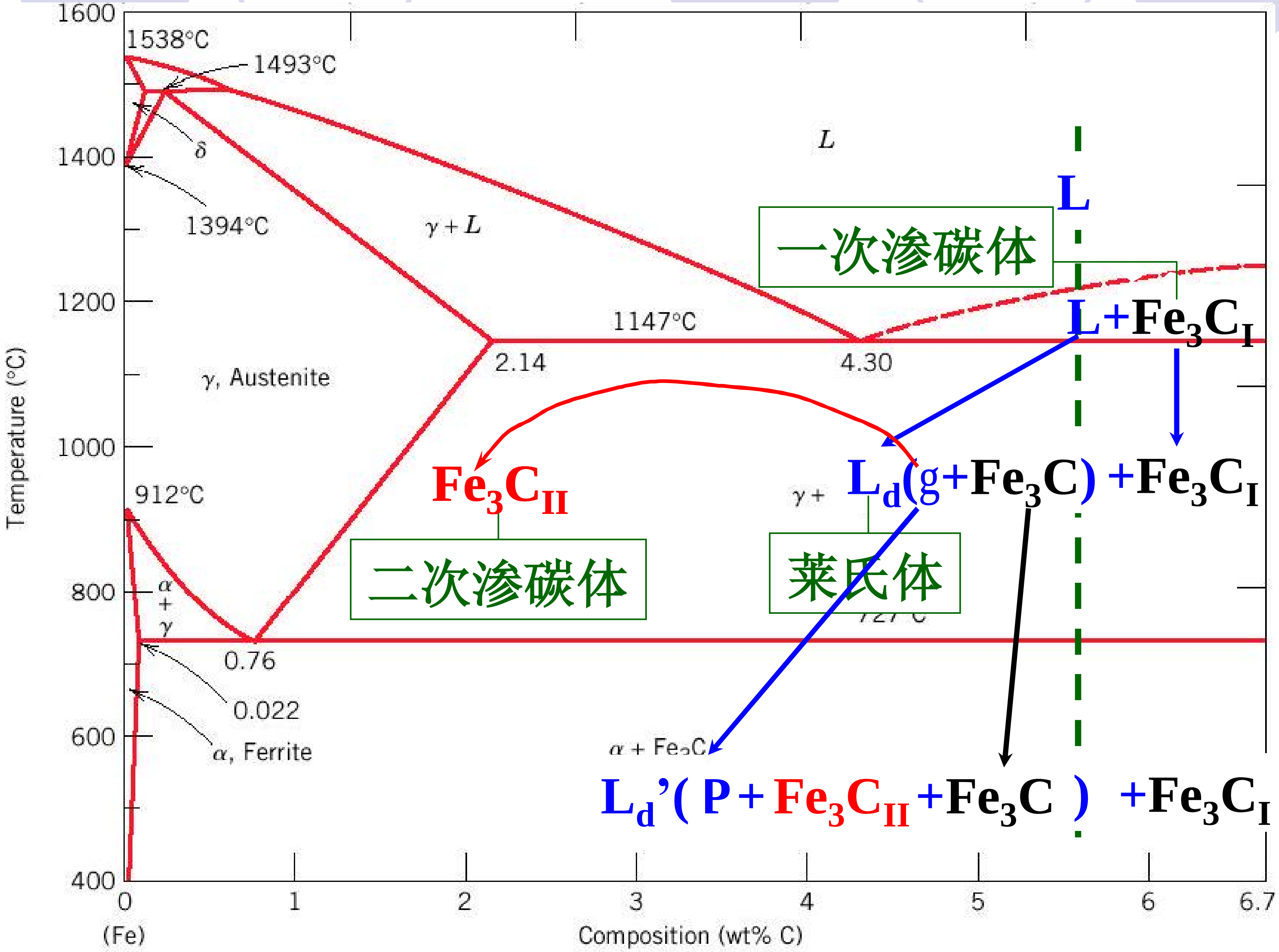
HYPEREUTECTIC



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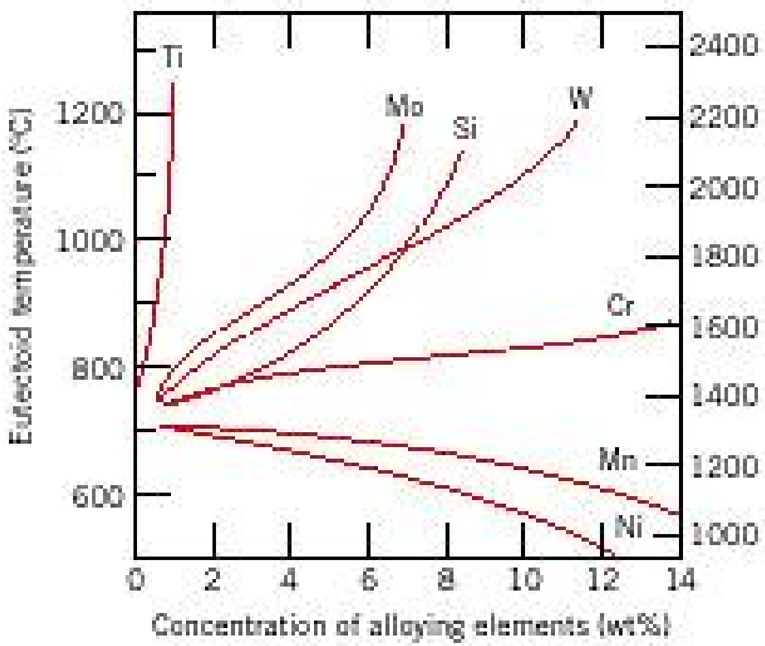
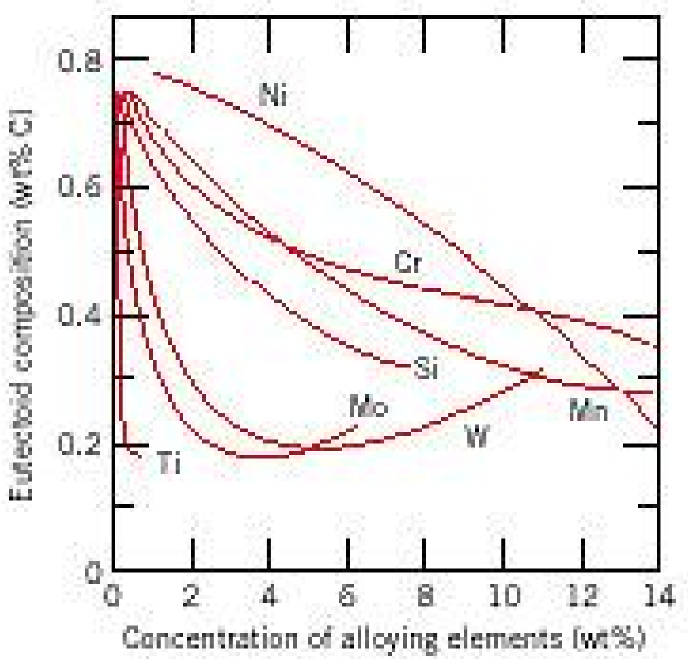
INFLUENCE OF ALLOYING ELEMENTS

- Addition of alloying elements affects the position of eutectoid with respect to temperature and to carbon concentration.
- The purpose of alloying: improve corrosion resistance, and/or render amenable to heat treatment.





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